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# The potential impact of seal and seabird predation on North American Atlantic salmon 

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## ABSTRACT

This paper seeks to determine whether seal and seabird predation could have caused the major decline in prefishery abundance of North American Atlantic salmon. Growth rates of marine-phase salmon were modeled as a series of logistic curves. Numbers of salmon alive were modeled by applying a size-based mortality function to estimates of North American smolt runs and subsequent adult pre-fishery abundance. The biomass of North American post-smolts estimated for the 1990s increased sharply during the summer to peak at 1,400-1,800 t in late fall.

Windows of predation vulnerability were taken as periods when salmon and seals or seabirds spatially coexist, and salmon are of a size taken by the predator. All seals and seabirds considered in this paper take smolt-size prey. Seals take marine-phase salmon of all sizes, but birds are constrained to smaller prey, and post-smolts outgrow predator capability by mid-June to fall, depending on the species. Vulnerability windows extend year-round for harbour and harp seals, in spring-summer-fall for grey seals, and in winter-spring for hooded seals. Vulnerability windows to birds run from river exit to the time when postsmolts are too large to eat.

Despite large sampling effort, salmon remains have been found in only two harp seal stomachs, two grey seal stomachs, one harbour seal stomach, and one common murre stomach in the Northwest Atlantic. Four other records from grey seals may reflect fish stolen from nets.

Potential impact of seal and seabird predation on marine-phase salmon was modeled under scenarios where predators took given percentages of prey biomass. If all seal and seabird predators combined remove 100\% of a post-smolt cohort, the post-smolts would constitute $0.04 \%$ of their diet. The predator with the largest consumption is the harp seal. If harp seals take $100 \%$ of a post-smolt cohort, then post-smolts would be $0.09 \%$ of their diet.

Seals and seabirds in the Northwest Atlantic could harvest a high percentage of marine-phase salmon, even though salmon is a rare item in their diets. Given the rising populations of seals and some seabirds it is plausible that seal and seabird predation could have caused the decline in pre-fishery salmon numbers. However, present data are insufficient to determine whether this in fact occurred.

## RÉSUMÉ

Ce document cherche à déterminer si la prédation par les phoques et par les oiseaux marins aurait pu causer le déclin majeur dans l'abondance pré-pêche du saumon de l'Atlantique Nord-Américain. Le taux de croissance du saumon durant sa phase marine était modélisé comme une série de courbes logistiques. Le nombre des saumons vivants étaient modélisé à l'aide d'une fonction de mortalité basée sur la taille corporelle, les estimés des saumoneaux qui sortaient des rivières, et l'abondance des adultes avant la pêche. La biomasse estimée des post-saumoneaux durant les années 1990 a augmenté de façon marquée durant l'été pour atteindre un maximum de 1,400-1,800 t tard en automne.

Les fenêtres de vulnérabilité à la prédation étaient considérées comme étant les périodes durant lesquelles
les saumons étaient dans la même place que les phoques ou les oiseaux marins, et les saumons avaient une taille convenable aux prédateurs. Tous les phoques et tous les oiseaux marins considérés dans cette analyse consomment les proies de la taille d'un saumoneau. Les phoques consomment les saumons en phase marine de toute taille, mais les oiseaux marins sont limités aux petites proies, et les post-saumoneaux deviennent trop gros pour eux entre le mi-juin et l'automne, dépendant de l'espèce d'oiseau. Les fenêtres de vulnérabilité sont ouvertes à l'année longue pour les phoques communs et les phoques de Groenland. Elles sont ouvertes en printemps-étéautomne pour les phoques gris et en hiver-printemps pour les phoques à capuchon. Les fenêtres de vulnérabilité aux oiseaux s'étendent de la sortie des rivières jusqu'au moment où les poissons sont trop gros à manger.

Malgré un grand effort d'échantillonage, les restants des saumons ont été trouvés seulement dans deux estomacs du phoque de Groenland, deux estomacs du phoque gris, un estomac du phoque commun, et un estomac d'une marmette commune dans le nord-ouest de l'Atlantique. Quatre autres records provenant des phoques gris auraient pu être originaires des poissons volés des filets.

L'impact potentiel de la prédation des phoques et les oiseaux marins était modélisé dans les scénarios dans lesquelles les prédateurs consomment les certains pourcentages de la biomasse de la proie. Si les phoques et les oiseaux marins enlèvent $100 \%$ d'une cohorte de post-saumoneaux, les post-saumoneaux constitueraient $0.04 \%$ de la diète des prédateurs. Le prédateur avec la plus grande consommation est le phoque de Groenland. Si ce prédateur consomme 100\% d'une cohorte des postsaumoneaux, les post-saumoneaux seraient $0.09 \%$ de leur diète.

Les phoques et les oiseaux marins du nord-ouest de l'Atlantique pourraient récolter un fort pourcentage des saumons en phase marine, même si le saumon est rare dans leurs diètes. Étant donné que la population des phoques et de certaines espèces d'oiseaux marins sont en état de croissance, il est plausible que la prédation par les phoques et par les oiseaux marins aurait pu causer le déclin des saumons au stade pré-pêche. Pourtant, l'information présentement disponible est insuffisante pour déterminer si ceci est le cas.

## INTRODUCTION

Pre-fishery abundance of Atlantic salmon of North American origin has declined two-fold or more since the early 1980s (Anon. 1999a, Marshall et al. 1999). At the same time, densities of juvenile salmon in many major rivers have remained strong, and in some cases increased. This suggests that the increased mortality occurs either during the pre-smolt winter, or (more likely) during the salmon's estuarine or marine phases.

Dempson et al. (1998) reviewed legal and illegal fisheries, marine environmental conditions, disease, parasites, and predation as possible causes of the decline. No evidence was found to clearly link any of these factors to the salmon decline. However, it was noted that the decrease in salmon returns has coincided with major changes in the physical and biological environment of the Northwest Atlantic. Such changes when acting at the ecosystem level may be termed "regime shifts," which are commonly followed by declines in the productivity of some species and increases in others (Steele 1996).

One of these changes is an increase in numbers of seals and certain species of seabirds. A few dietary studies of seabirds and seals in eastern Canadian waters have reported salmon in small, usually trace, amounts, but most have reported no salmon at all. This suggests that salmon is of inconsequential importance to these predators. However, it does not necessarily follow that the predators are of inconsequential importance to salmon.

The main purpose of this paper is to determine whether seal and seabird predation could be of sufficient magnitude to cause, or be a major contributor to, the decline of North American Atlantic salmon returns. It must be emphasized that the paper is an examination of plausibility only, because current data are insufficient to determine whether seals and seabirds are causative agents in the salmon decline.

To achieve this purpose we a) estimate the numbers and biomass of post-smolt salmon in the sea, b) determine times and locations of salmon vulnerability to seal and seabird predation, c) review available records of salmon predation by seals and seabirds, and d) determine whether current dietary sampling programs are adequate to measure salmon predation by seals and seabirds. We also identify research endeavors likely to shed light on the effect of seal and seabird predation on salmon populations.

Due to their particular mode of feeding, northern gannets appear to have the highest likelihood of any seal or seabird species of capturing salmon. Potential effects of gannet predation on salmon are evaluated separately (W.A. Montevecchi unpubl.). In the present paper, seabirds are taken to include species whose foraging habitat includes the offshore zone. This excludes great and double-crested cormorants, which are exclusively inshore and estuarine in their marine distribution. The post-smolt stage of Atlantic salmon refers to the period between river exit and 31 December of the same year.

## DISTRIBUTION, GROWTH, AND BIOMASS OF SALMON AT SEA

Marine migrations of North American Atlantic salmon
With the exception of salmon from inner Bay of Fundy rivers which complete their life cycle in the Fundy-Gulf of Maine region, salmon from west Atlantic rivers appear as 1 sea winter adults in the general area of the Labrador Sea (Reddin 1988, Ritter 1989). Our understanding of post-smolt movements between home rivers and the Labrador Sea is based on limited information from research fishing in the northwestern Gulf of St. Lawrence and the Labrador Sea, returns of tags from commercial fishers, and from predation records (Allen et al. 1972, Reddin 1988).

Ritter (1989) compiled post-smolt tag returns from Quebec, Maritime, and New England rivers by month and capture location. There were 306 recoveries of tags applied to smolts in the Saint John River and rivers in Maine (Table 1) (recoveries with unknown recapture dates are excluded). Most (283, 92.5\%) of these occurred in the Atlantic coast south of the Gulf of St. Lawrence. Twenty-one (6.7\%) came from Labrador and the Atlantic coast of Newfoundland, and two (0.7\%) came from the west coast of Newfoundland. Recoveries from south of the Gulf (Atlantic coast of Nova Scotia, Bay of Fundy, Gulf of Maine) were reported in June to October, and recoveries in the Gulf and north were reported in June to September. In all zones (south of Gulf, Gulf, north of Gulf) more than $50 \%$ of recoveries were reported in July.

More than half (42 of 77) of recoveries of tags applied to smolts in Southwest Nova Scotia rivers occurred in the mouths of home rivers (Table 1). Of the remaining 35 recoveries, 27 (77.1\%) occurred in Fundy or Atlantic Nova Scotia waters. Four (11.4\%) came from the northeast and south coasts Newfoundland, two from Labrador ( $5.7 \%$ ), and two ( $5.7 \%$ ) came from the Lower North Shore of the Gulf of St. Lawrence. Nova Scotia recoveries were reported from June to September, with a peak in June. All Newfoundland and Gulf recoveries were in July, and the Labrador recoveries were in August and September.

About half (19 of 37) of tag recoveries for post-smolts in the Gulf of St. Lawrence came from home river mouths (Table 1). Of the remaining 18, 11 (55.0\%) came from within the Gulf, two (10.0\%) came from the east side of Cape Breton Island, one (5.0\%) came from the Southern Shore of the Avalon Peninsula, one (5.0\%) came from the east side of the Great Northern Peninsula, and three (15\%) came from southern Labrador. Gulf recoveries were reported in June to October, Cape Breton and Newfoundland recoveries were reported in June-July, and in Labrador recoveries in August-September (Ritter 1989).

On the basis of tag recoveries at seabird colonies on the Avalon Peninsula and the northeast coast of Newfoundland, Montevecchi et al. (1988) suggested that post-smolts from the Atlantic coast south of the Gulf of St. Lawrence migrate to the Labrador Sea by passing east of Newfoundland. However, the presence of post-smolts from the Saint John and the LaHave rivers in the
northeastern Gulf (Ritter 1989) suggests that a route to the west of Newfoundland may also be used.

Caron's (1983) tagging analysis suggests that postsmolts from the northwest Gulf of St. Lawrence migrate from west to east across the northern Gulf during the post-smolt summer, which implies that these fish will leave the Gulf through the Strait of Belle Isle. One tag applied in the Miramichi was recovered on the east side of the Great Northern Peninsula in July (Ritter 1989), which implies a similar route. A tag from the Gaspé Peninsula was recovered on the Southern Shore of the Avalon Peninsula in June or July, and a tag applied on the Margaree was found off eastern Cape Breton in June. These recoveries imply a route through Cabot Strait.

Research fishing with surface-set gillnets in 1987, 1988, 1991, and 1998 established that post-smolts are present in substantial numbers in September-October in the Labrador Sea, especially in the area between $56^{\circ}$ and $58^{\circ}$ (Reddin and Short 1991, Reddin unpubl. data). These fish include a wide range of river ages, which implies that post-smolts from a broad geographic area of North America are represented.

Post-smolts were also found in commercial and research fishing in inshore waters in the Baie Trinité-SeptÎles area of the northwestern Gulf in August-October 1982-1985 (Dutil and Coutu 1988). Because sampling occurred in only a very small area compared with Labrador Sea studies, no comparison can be made regarding the relative sizes of post-smolt populations occupying the Gulf and the Labrador Sea.

Reddin and Short (1991) suggested that post-smolts winter in the Labrador Sea, based on their presence there before and after winter, and the availability of water of suitable temperature. In their second summer at sea, fish destined to return as 2SW adults tend to move to the northern Labrador Sea and off the west coast of Greenland, although some remain in coastal Newfoundland waters (Reddin 1988). Fish which will mature as 1SW adults do not undertake this migration, and instead return to their natal rivers. Non-maturing adults return from Greenland in fall via the Labrador coast, and form concentrations in an area east of the Strait of Belle Isle. Further concentrations are found in the subsequent spring in the area east of the Grand Banks, suggesting that non-maturing 1SW adults winter in the general area of the Southern Labrador Sea and the northern Grand Banks (Reddin 1988).

Migratory patterns of adult Atlantic salmon are reasonably well known (except during winter) because of the history of directed commercial fishing. However, knowledge of post-smolt movements is sketchy at best. Tagging results are based on bycatch of commercial fisheries, which depend on the presence of gear capable of capturing post-smolts. Use of such gear is likely to vary seasonally and geographically. Return rates will also be affected by the increasing size of post-smolts, which determines their susceptibility to capture in a particular gear, and by the decreasing number of post-smolts due to natural mortality.

Because of these biases, available data cannot be used as a quantitative indicator of post-smolt migrations.

Nevertheless, several points emerge from the tagging data compiled by Ritter (1989): 1) In all cases, the majority of post-smolt tag reports came from the region where the tag was applied, and records from Newfoundland and Labrador accounted for a small portion of the total. This suggests that substantial numbers of post-smolts do not migrate out of their home region before fall. 2) Post-smolt migrations are diffuse in space and time. Tag records show no orderly progression of increasing distance from home region with time; instead peaks of recaptures occur simultaneously in local and distant (Newfoundland) waters. This suggests that some post-smolts migrate to the Labrador Sea soon after river exit while others remain in the region of their home river. 3) Migratory routes vary among post-smolts originating within the same river or region. Some Gulf post-smolts appear to use the Cabot Strait as a migratory route and some post-smolts from south of the Gulf appear to use the Strait of Belle Isle.

The records reviewed herein confirm the presence of post-smolts at certain times and places, but due to incomplete sampling, cannot confirm absence from other areas. Directed research fishing has been conducted only in the southern Labrador Sea and in the northwestern Gulf. Without similar efforts in other areas, the possibility that post-smolts form concentrations elsewhere cannot be excluded. Tagging records indicate that at least some post-smolts from Gulf of Maine, Scotian Shelf, and Gulf of St. Lawrence rivers spend summer and perhaps fall in their home regions. Whether these fish migrate to the Labrador Sea and winter there, or remain in their home regions and find deep-water wintering sites with suitable temperatures, is unknown.

For the purpose of determining windows of predation vulnerability, it is assumed that post-smolt salmon occupy the Fundy-Gulf of Maine area, the Scotian Shelf, the Gulf of St. Lawrence, banks around Newfoundland, and the Labrador Sea during their post-smolt summer. It is further assumed that all post-smolts (other than inner Bay of Fundy populations) migrate to the Labrador Sea by 31 October, and winter there.

## Growth rates of salmon at sea

Marine-phase growth of Atlantic salmon was modeled with a series of logistic curves, with the ascendant portion of the combined curve representing summer growth and the asymptotic portion representing winter growth quiescence (Figs. 1-4). Curves were fitted to the following anchor points:

| Date | Sea <br> age $(\mathrm{d})$ | Fork <br> length <br> $(\mathrm{cm})$ | Weight <br> $(\mathrm{g})$ |
| :---: | :---: | :---: | :---: |
| 1 Jun | 0 | 13.75 | 20.8 |
| 9 Aug | 70 | 23.4 | 195.9 |
| 1 Oct | 123 | 36.4 | 555 |
| 1 Jul | 395 | 52.5 | 1,580 |
| 1 Jul | 760 | 73.4 | 4,430 |

The logistic equations (Pitcher and Hart 1982) are:

$$
L_{t}=C+\frac{L_{\infty}}{1+---\cdots----e^{-g\left(t-t_{0}\right)}}
$$

for length and

$$
W_{t}=C+\frac{W_{\infty}}{1+----\cdots-\cdots--e^{-g(t-t)}}
$$

for weight.
For length (cm), equation parameters are:

| Stanza |  |  |  |  |  |
| :---: | :---: | ---: | ---: | ---: | ---: |
|  | Sea age <br> (d) | C | $\mathrm{L}_{\infty}$ | g | $\mathrm{t}_{0}$ |
| 1 | $0-272$ | 11.73 | 32.78 | 0.031 | 86.8 |
| 2 | $273-636$ | 43.7 | 25 | 0.024 | 149 |
| 3 | $>636$ | 68.4 | 80 | 0.026 | 230 |

For weight (g), equation parameters are:

| Stanza | Sea age <br> (d) | $C$ | $\mathrm{~W}_{\infty}$ | g | $\mathrm{t}_{0}$ |
| :---: | :---: | :---: | :---: | ---: | ---: |
| 1 | $0-272$ | -10.4 | 1146 | 0.0286 | 124.86 |
| 2 | $273-636$ | 1105 | 2750 | 0.029 | 177 |
| 3 | $>636$ | 3830 | 5000 | 0.029 | 193 |

River exit date was taken as 1 June. River exit measurements were taken in the Miramichi by Allen et al. (1972) (lengths) and by R.A. Cunjak, University of New Brunswick, unpubl. (weights). Measurements for August were made on 21 post-smolts recovered from a northern gannet colony on Funk Island, off the northeast coast of Newfoundland, on a mean date of 9 August (W.A. Montevecchi unpubl.). Length measurements (cm) were converted to weight $(\mathrm{g})$ by the equation $0.1807^{*}$ length ${ }^{2.213}$, which was derived from measurements of post-smolts captured in fall research cruises in the Labrador Sea. Measurements for October were the means of lengths and weights recorded in these cruises ( $n=375$ ). Measurements for sea ages 395 and 760 d were from virgin 1SW and 2SW salmon returning to the Miramichi River (Moore et al. 1995).

Growth curves fitted in this way were similar to those based on post-smolt records from the Bay of Fundy (Allen et al. 1972) (Fig. 1). However, plotted growth was much higher than growth reported for post-smolts in the northwestern Gulf of St. Lawrence by Dutil and Coutu (1988) (Figs. 1 and 3). In mid-August, the two curves differed by a small margin, but by October Labrador Sea post-smolts were nearly double the weight of those from the northwestern Gulf.

## Numbers and biomass of post-smolt salmon

Estimating numbers of post-smolts alive through time requires knowledge of the initial population, the final population, and a function that calculates mortality. Numbers of smolts leaving North American rivers in 19771996 were estimated as follows. Percentages of exiting wild smolts that return as 1SW adults are available for 10 Canadian rivers (Table 2). Not all rivers have data for the full time series, and some rivers may have higher return rates than others. This means that biases could be
introduced if return rates for each year were simply the raw means of available data. Correction factors for missing years were calculated by dividing the mean of directly measured return rates for the site by the mean return rate for other sites for the same years (Table 2). Missing return rates were estimated as the product of the correction factor and the mean of available return rates in the same year.

Return rates could be subject to an additional bias because the proportion of salmon returning after various sea ages varies regionally. This means that a region with a high proportion of multiple sea winter returnees is likely to have a lower rate of 1SW returns than a region with few MSW returnees. To avoid this bias, return rates were weighted by the ratio of the proportion of returnees coming at 1SW for individual rivers, to the overall proportion of 1SW returnees among the North American returning salmon population (Table 2). Overall return rates to 1SW were taken as the mean of these weighted return rates.

Number of salmon returning to North American rivers at age 1SW was taken from ICES compilations (Anon. 1999a). The North American smolt run was estimated by dividing 1SW returns by the smolt to 1SW return rate (Table 3).

Number of salmon alive on 1 July in their 1SW year was taken as the sum of ICES estimates of pre-fishery maturing and pre-fishery non-maturing 1SW fish (Anon. 1999a) (Table 3).

Natural mortality of fishes is strongly influenced by size, with large fish suffering lower mortality rates than small ones (Doubleday et al. 1979, McGurk 1986, Anderson 1988, Mangel 1994). Numbers of salmon alive between river exit and 1 July in the 1SW year were modeled with Lorenzen's (1996) weight-based mortality function: $\quad M_{w}=M_{u} W^{b}$, where $M_{w}$ is instantaneous mortality at weight, $M_{u}$ is natural mortality at unit weight, and $b$ is the allometric scaling factor. Using literature values for ocean fish, Lorenzen (1996) calculated $M_{u}$ as 3.69 and $b$ as -0.305 , with mortalities annual and weights in grams. For each cohort, numbers of salmon alive were calculated for each day between river exit and 1 July of the 1SW year, using the estimated North American smolt run as a starting point. Daily mortalities were calculated by the Lorenzen equation, using modeled weights (Fig. 4), the allometric exponent for ocean fish, and an arbitrary value of $\mathrm{M}_{\mathrm{u}}$. Populations alive each day were reduced by the mortality calculated for the previous day. The actual mortality schedule and number alive were estimated by iteratively varying $M_{u}$ (using Microsoft Excel's Goal Seek function) until the final population matched the estimated prefishery abundance for 1SW fish.

Post-smolts commonly encounter high levels of predation when they enter estuaries; osmotic stress may exacerbate their vulnerability to capture (Larsson 1985, Hislop and Shelton 1993). Mortality and number alive were modeled for scenarios with no mortality upon river exit, with $20 \%$ mortality upon river exit, and with $40 \%$ mortality upon river exit.

In all three scenarios, estimated daily mortalities and number alive declined steeply in the post-smolt summer,
as the fish rapidly gained weight (Table 4, Figs. 5-6). Calculations based on averaged values for 1990-1996 indicate a late fall population of about 2,000,000 (Fig. 6). Mortality leveled off during the period of slow growth in the winter, but numbers continued to decline during this period, albeit much less rapidly than during the post-smolt summer. Initially, numbers of post-smolts alive diverged broadly among the three scenarios of river exit mortality, but by late fall these differences had been largely erased. This is due to the stabilizing effect of the final population, which was held constant in all scenarios.

Biomass was calculated as the product of number alive and daily weight at age. Based on averaged values for 1990-1996, biomass in the three scenarios rose from about 200 t at river exit to about 1,400-1,800 t in late fall (Table 5, Fig. 7). Biomass declined over winter because of minimal growth and continuing mortality.

## WINDOWS OF VULNERABILITY TO SEAL AND SEABIRD PREDATION

Predation can take place only if the prey is within the size range taken by the predator, and the predator and prey co-occur in time and space. Acceptable prey size ranges can be deduced from examination of prey taken by predators. Lengths of prey taken by seals and seabirds are typically calculated from otoliths found in predator stomachs. Minimum prey sizes based on otolith dimensions were $3-7 \mathrm{~cm}$ for grey seals, $5-10 \mathrm{~cm}$ for harbour seals, 2 cm for harp seals, and 13.4 cm for hooded seals (Table 6, see also Anon. 1999c). These sizes are smaller than smolts at the time of sea exit, which indicates that smolts are within the size range taken by these predators. Maximum reported prey sizes, based on otolith examination, were 79.7 cm for grey seals, $50-55 \mathrm{~cm}$ for harbour seals, 57 cm for harp seals, and 48.1 cm for hooded seals (Table 6). The otolith method of calculating prey size selection assumes that the predator will consume the entire fish, including the head. If heads are discarded, the method will underestimate the maximum size of acceptable prey. Boulva and McLaren (1979) observed harbour seals eating large fish in pieces at the surface. On the basis of the low number of otoliths found, they concluded that heads were often left uneaten. In Scotland, grey and harbour seals often eat salmon in pieces, leaving the head and much of the skeletal material (Pierce et al. 1991a, 1991b, 1997; Shearer 1992). However most Scottish reports of seal predation on salmon appear to refer to consumption of net-caught fish (Boyle et al. 1990). On 30 April 1984, Reddin (unpubl. data) observed a harbour seal eating an adult salmon in Aberdeen Harbour, Scotland. Only the soft parts were consumed and the head and backbone were discarded.

Heads of large fish are not always rejected. Grey seals on Anticosti took cod up to 79.7 cm , estimated from otolith length (Table 6), and captive grey seals feeding on adult salmon have been observed to consume the head (Pierce et al. 1997). Pemberton et al. (1994) reported that harp seals feeding on cod (mean length 49 cm ) spilling from a trawl swallowed them headfirst and whole. They also reported observations of captive harp seals
holding large cod (length not given) in their foreflippers and eating them, beginning with the belly. Fragments which fell away were recovered and the entire fish was eaten.

On the basis of these observations, it appears that adult salmon fall within the size range taken by harbour, grey, and harp seals. We have located no reports of visual observations of hooded seals eating large fish, but on the basis of the hooded seal's large size, it seems likely that they would do so.

Minimum prey sizes of northern fulmars, black-legged kittiwakes, herring gulls, glaucous gulls, common murres, and thick-billed murres are much lower than smolt size (Table 7). Minimum prey size reported for great blackbacked gulls was 19 cm , which is larger than smolt size (Table 7). However in this study fish of smolt size were unavailable. Given the omnivorous habits of gulls, it is likely that all seabirds considered in this paper consume smolt-size fishes.

Maximum prey sizes for seabirds are much lower than those of seals (Table 7). Live prey taken by northern fulmars was consistently smaller than 17 cm in several studies, but the single study in which trawl samples were available indicated this was the maximum size locally available. Hence the true upper limit of live prey size could be larger than this. Fulmars are capable of swallowing much larger items; birds scavenging on fishery discards took fish up to 30 cm long. This is a major increase over maximum sizes in live prey studies, but it is possible that fulmars can handle large prey only when it is dead. Greater shearwaters have been found to take fish and squid up to 20 cm . It is presumed that sooty shearwaters have a similar size selection. Black-legged kittiwakes have been found to take prey up to 16 cm . Herring gulls and great black-backed gulls take prey up to 30 and 39 cm respectively. Maximum prey size of glaucous gulls is only 13.5 cm , but available prey were no bigger than this. Based on their size, it is likely that they can take much larger prey, perhaps of the range of herring gulls. Common murres take prey up to 17 cm and thick-billed murres take prey up to 19 cm .

Size limits noted above were converted into dates on the basis of calculated weight at sea age (Figs. 1 and 2).

Marine distributions of seal and seabird species are reported by Hammill and Stenson (1997) and Diamond et al. (1993), respectively. Although grey seals are increasingly being reported in Labrador, they are common and widespread only in the Gulf of St. Lawrence and in the Atlantic south of the Gulf. Post-smolts are assumed to vacate this area in the winter. Hence grey seals produced a split vulnerability window, with predation potentially occurring in the post-smolt summer and fall, and in the following year when 1SW fish return toward natal rivers in the Gulf and Maritimes (Table 8). Harbour seals are resident in the Gulf, the Maritimes, and Newfoundland, and hence co-occur with salmon throughout the year. Their vulnerability window therefore includes their entire marine phase. Most harp seals move south from the Arctic in fall and early winter, occupying Gulf and Newfoundland waters until spring when they return north. However, 5\% of harp seals are thought to
remain in southern waters year-round (Hammill and Stenson 1997). Thus the salmon vulnerability window to harp seal predation includes the entire marine phase. Hooded seals are in southern waters from late fall to spring. Their vulnerability window therefore runs from December of the post-smolt year to May of the 1SW year.

Because of their smaller prey size limits, birds can prey on salmon only during the post-smolt year (Table 8). Post-smolts out-grow the size limits of kittiwakes in June, and the size limits of fulmars, common murres, and shearwaters in July. Salmon do not have a vulnerability window to thick-billed murres because this species is on its northern breeding grounds at the time when salmon are small enough to be taken. Herring and great-blacked backed gulls can take larger food than the other seabird species, and can prey on post-smolts into the fall.

## RECORDS OF SALMON PREDATION BY SEALS AND SEABIRDS

We have located 10 records of Atlantic salmon predation from seal and seabird stomachs in eastern Canada (Table 9). Four of these occurred in the Miramichi estuary from 1950 to 1970. Seals commonly rob salmon from gillnets (Rae and Shearer 1965, Reddin and Felt 1998), so it is uncertain whether the Miramichi records represent wild-caught fish. There are two records of grey seal predation on salmon that cannot be explained by net-stealing. One is from the Magdalen Islands and the other is from Anticosti Island where otoliths from six salmon were found in one stomach. A tag that had been applied to a smolt was found in a harbour seal stomach in the Bay of Fundy. Salmon remains were found in two harp seal stomachs, one in the St. Lawrence estuary and one on the northeast coast of Newfoundland. Finally, a tag was found in a common murre stomach from eastern Newfoundland.

In addition to the 10 records noted above, Comeau (1909) reported finding salmon in a harp seal stomach, and stated that grey seals raid salmon nets.

Lengths of salmon were estimated from otoliths removed from three predator stomachs (Table 9). In all cases the calculated lengths were smaller than the size range expected at that time of the year (although the largest Anticosti size might be a small grilse). This suggests that either a) inappropriate otolith-length relations were used, b) erosion of the otoliths biased the length calculations, or c) otoliths came from a species other than Atlantic salmon. Tollit et al. (1997) showed that erosion of otoliths substantially altered the relation between otolith size and fish size, and required the use of correction factors ranging from 9 to $30 \%$ for otoliths of medium digestion grade.

The report of harp seal predation in the St. Lawrence estuary came at an unexpected time (mid-April), which casts some uncertainty on the record.

Two of the records were based on personal communications, and were not mentioned in the papers that presented the dietary studies that obtained the records (Bowen and Harrison 1996, Piatt 1987). In both cases (harbour seal in Fundy, murre in Newfoundland) the artifact found was a salmon tag, leaving no doubt as
to prey identity. This suggests that diet investigators may not necessarily report prey that is unusual, or does not match the format in which other data are presented (i.e. a tag would not readily fit in a table reporting otolith records).

In addition to stomach analysis, evidence for seal predation is available from six sight records of seals pursuing, holding, or eating salmonids in Newfoundland and Labrador (Table 10). Two of the Newfoundland/ Labrador records occurred in areas where commercial fishing was permitted, leading to the possibility that the salmon observed in the seal's mouth was stolen from a net. In the remaining four cases there were no fishing nets in the vicinity; hence these observations can be taken as valid records of predation on free-swimming fish. Two of the records involved adult salmon and one involved a juvenile salmonid (either trout or salmon). One record was of a seal pursuing an adult salmon into a trap. Three observations came from rivers and estuaries in Labrador, where seal presence commonly coincides with salmonid runs.

Diet studies provide good temporal and spatial coverage for grey and harp seals in eastern Canada (Table 11), although some significant gaps remain (Hammill and Stenson 1997). Coverage is less extensive for harbour and hooded seals. Published diet investigations have not been designed to measure salmon predation, and no study has targeted the estuaries of major salmon rivers where seals might prey on exiting smolts and kelts or returning adults.

Some papers explicitly report only major prey species, and ignore the rare ones like Atlantic salmon (Table 11). Sample size of food-containing grey seal stomachs totaled 1,315 , although sample sizes are difficult to sum with certainty because some papers incorporate data from previous studies (Table 11). Of these, 1,094 samples were reported in papers which indicated that all prey were reported. Sample size of harbour seal stomachs is 659. All papers indicate full data disclosure, although the tag found in a stomach (Table 9) was not reported. Published reports of harp seal stomachs containing food total 3,145 ( 2,083 with full identification), but this figure is uncertain due to authors' inclusion of previous works. Sample size of food-containing harp stomachs in DFO files, including unpublished records, currently total about 6,100 (G. Stenson, DFO, pers. comm., April 1999).

Most diet studies of seabirds are conducted in the summer, which is advantageous from a salmon research point of view because that is when salmon are small enough for birds to eat. Nevertheless spatial coverage is poor for all species. The largest sample size is for common murres (Table 12) ( $\mathrm{N}=4,778$ ). The species with the poorest coverage are the shearwaters, which have not been sampled since 1978, and the fulmar, which has not been sampled at all in eastern Canada (Hatch and Nettleship 1998). No seabird diet studies have focused on the areas around the mouths of salmon rivers.

## SEAL AND SEABIRD HARVEST IN RELATION TO SALMON BIOMASS

Hammill and Stenson (1997) estimated that grey, harbour, harp, and hooded seals consume 3.8 million $t$ of food annually in eastern Canadian waters south of midLabrador. Eighty-two percent of this ( 3.1 million $t$ ) is due to harp seals (Table 13).

Seabird harvest has been estimated as 707,284 t for NAFO area 2J3KLNO, which runs from the mid-Labrador coast to the southern Grand Banks (Anon. 1999b), and as 80,102 and $108,419 \mathrm{t}$ in the Gulf of St. Lawrence (locally breeding population only; Cairns et al. 1991 and Anon. 1999b, respectively). Total seabird harvest in eastern Canadian waters has not been estimated. However, Diamond et al. (1993) estimated seabird energy demand for eastern Canadian waters south of $60^{\circ} \mathrm{N}$, and tabulated this demand by time period, geographical area, and predator species (or group of species). Diamond et al. (1993) noted that their energy demands for the "Labrador Sea" (from the edge of the continental shelf east to $45^{\circ} \mathrm{W}$ and north to $60^{\circ} \mathrm{N}$ ) are likely overestimated because their data set oversampled the area near the continental shelf where birds tend to congregate. To compensate, we reduced energy demand in this area by $50 \%$. We converted Diamond et al.'s (1993) energy demands into harvest tonnage by assuming an energy density of 5.1 $\mathrm{kJ} / \mathrm{g}$ wet weight (Cairns 1998). This yields a total annual seabird harvest of 2.4 million $t$ south of $60^{\circ} \mathrm{N}$ (Table 14).

Prey harvest by seals and seabirds was calculated for salmon vulnerability windows by summing harvest within the time period of vulnerability and for the geographic areas where salmon and the predator coincided (Table 13), using the harvest figures of Hammill and Stenson (1997) for seals and the re-analysis of Diamond et al.'s (1993) data (Table 14) for birds. Mean salmon biomass was then calculated for these periods of vulnerability, based on 1990-1996 data and assuming a 20\% mortality on river exit (Table 5).

Percent of salmon in predator diet was calculated for scenarios in which the predator consumes $1 \%, 10 \%$, and $100 \%$ of the salmon cohort. For seals, predation of postsmolts (prior to 1 January) and 1SW fish (after 1 January) was analysed separately. When the predator was assumed to consume $1 \%$ of the salmon cohort, salmon occupied $0.16 \%$ to $0.31 \%$ of the diet of harbour seals (Table 13). For all other species, salmon occupied less than $0.05 \%$ of diet during windows of salmon vulnerability. Under this scenario, post-smolts contributed 0.0009\% and 1SW salmon contributed $0.0003 \%$ to harp seal diet. For species other than harbour and harp seals, salmon as a percentage of total prey ranged from $0.038 \%$ (blacklegged kittiwakes) to 0.0026\% (common murres).

Scenarios in which predators consumed 10\% and $100 \%$ of salmon cohorts gave results which varied by one and two orders of magnitude, respectively, from those of the $1 \%$ consumption scenario. If harp seals consume $10 \%$ of the post-smolt population, then salmon will be $0.009 \%$ of diet. If harp seals consume $100 \%$ of postsmolts, then salmon will be $0.09 \%$ of diet. If harp seals
consume $10 \%$ or $100 \%$ of 1SW salmon, then salmon will constitute $0.003 \%$ and $0.03 \%$ of prey, respectively.

Taking seal and seabird predators as a whole, and assuming that predation removes $1 \%$ of the salmon cohort, salmon would be $0.0004 \%$ of prey (Table 13).

Predator harvest of Atlantic salmon was estimated on the basis of the five records of seal and seabird predation since 1980 (Table 9). Salmon as a percent of total annual diet was estimated as numbers of salmon per stomach divided by the mean number of fish prey per stomach, all divided by the number of fully identified prey samples available for the predator in eastern Canadian waters (Table 15). These calculations are based on frequency of occurrence. Salmon contribution to harp seal diet at Les Escoumins (Beck et al. 1993) was available as percent by mass. Salmon as a percent of diet from this record was added to the salmon percent of diet value from the other harp seal predation record (from Brighton, Newfoundland).

Estimates of salmon as a percent of diet ranged from $0.0034 \%$ for harp seals to $0.389 \%$ for grey seals (Table 15). Application of these percents to total annual consumption of all prey species yielded salmon harvest estimates of $1,090 \mathrm{t}$ for grey seals, 1.3 t for harbour seals, 106 t for harp seals, and 67 t for common murres. Comparison of these estimated harvests to salmon biomass during their windows of vulnerability indicated that grey, harbour, and harp seals and common murres eat $117,0.1,10.3$, and $26.1 \%$, respectively, of salmon biomass.

Hammill and Stenson (1997) estimated salmon predation by seals as part of their food consumption model. According to their model, grey seals consume 712 t of salmon ( $76 \%$ of biomass), and harp seals consume 2,474 t of salmon (240\% of biomass).

## DISCUSSION

Limitations to reliability
This study uses inference and results of energetics modeling to evaluate predation potential of seals and seabirds on salmon. The analysis is subject to errors and biases which may inflate, deflate, or alter in unpredictable directions the likely importance of seal and seabird predation to salmon. Major sources of error follow.

Factors which may lead to an overestimate seal and seabird impact on salmon:
a) Misidentification as salmon - For all three otolith records in seal stomachs, calculated lengths were unexpectedly small for the time of the year. This could mean that the otoliths were from species other than salmon (possibly sea trout). Alternatively, lengths may have been underestimated due to otolith erosion (salmonid otoliths are friable and erode readily; Boyle et al. 1990; see also Tollit et al. 1997).
b) Long retention of tags - Two of the records (harbour seal and common murre) were of tags. If tags are retained in stomachs longer than otoliths, then percent salmon in diet would be upwardly biased.
c) Predation risk altered by tags - Tags may increase the visibility of prey or impair its escape response, leading to increased vulnerability to predation. If the fish bearing the tags which were discovered in the harbour seal and murre stomachs were captured because they bore tags, then the percent of salmon in diet would be upwardly biased.
Factors which may lead to an underestimate of seal and seabird impact on salmon:
a) Incomplete reporting-Some studies note that only major prey species are reported. Studies that do not mention this may nevertheless also not present some data, given that two of the five post1980 records are from personal communications, and were not mentioned in the diet studies that published other results. If some studies indicate that all results are reported but in fact they are not, then sample size will be inflated above its true value and harvests will be underestimated.
b) Failure to identify - Those assigned to stomach examination are more likely to accurately identify prey items which are common, even when they are in poor condition, than those that are rarely seen. Thus salmon otoliths, especially those in poor condition, might not be identified as such.
c) Missing heads - Seal predation on adult salmon will not be detected by otolith-based diet studies if heads are discarded, as has been observed in adult salmon and other large fish (Boulva and McLaren 1979, Pierce et al. 1991b, Reddin unpubl.).
Factors which lead to errors in either direction:
a) Sampling error - One or two records per predator is insufficient to reliably indicate percent salmon in predator diet.
b) Use of frequency of occurrence data - Counts of prey items accurately indicate proportion of diet only if the prey items are of similar size. This is unlikely to be the case.
c) Vulnerability windows to predators are calculated on the basis of simple length cut-offs. Instead, the actual upper size limit that predators can take is likely to be graduated (analogous to partial recruitment), with salmon progressively less vulnerable with increasing size. Cut-offs based on otolith analysis ignore possible delayed mortality due to predation attempts in which the salmon escapes, but subsequently dies of wounds.
d) Estimates of seal and seabird harvest generated by bioenergetics models are subject to substantial error (Shelton et al. 1997, Cairns and Kerekes in press).

Seals and seabirds as salmon predators
Despite the limitations noted above, there is sufficient bulk of evidence presented in this study to demonstrate that seals and seabirds are significant potential predators on North American Atlantic salmon during their marine phase. It is shown that post-smolt salmon are in a vulnerability window to seabird predation in the period following river exit, and that they are in the vulnerability
window of at least one seal species during their full time at sea. Vulnerability may be greater in certain local situations, such as Labrador rivers that have year-round populations of harbour seals. Ability of salmon to flee predators in freshwater will be restricted by the size of the river and number of ponds and deep pools.

Records of salmon in seal and seabird stomachs are rare (only five records since 1980), indicating that salmon are at most a minute fraction of predator diet. However, biomass of salmon in the sea is very small; hence predation which is insignificant to the predator may be very important to the prey. On the basis of available diet data, salmon harvest as calculated in two analyses was greater than the total biomass available (Table 15). This result underlines the unreliability of estimating harvest on the basis of a handful of prey capture records. Nevertheless, it reinforces the suggestion that these predators could account for the majority of the salmon's total marine mortality. This review does not include predation by northern gannets, which have specialized feeding adaptations for medium-size fish which swim near the water surface, which allow them to harvest significant quantities of salmon (W.A. Montevecchi unpubl.).

Although large sample sizes have been amassed in diet studies of some predators, currently available diet data are inadequate to reliably assess salmon contribution to predator diet, which is a precursor to determining proportion of salmon biomass that is harvested. This situation is unlikely to change. Because salmon are relatively rare in the ocean, predators can harvest substantial fractions of salmon biomass even if salmon constitute minute fractions of predator diet. For harp seals preying on 1SW salmon, a harvest of $10 \%$ of biomass corresponds to salmon contributing $0.003 \%$ of seal diet. In this scenario, only one out of 33,490 prey items would be a salmon (provided that salmon are the same size as other prey). Sampling programs sufficiently large to accurately measure salmon contribution to predator diet would have to be huge, and beyond the realm of the possible. This means that we cannot rely on conventional diet sampling, even if it substantially increases, to clarify the effects of seal and seabird predation on salmon populations.

Although this study gives evidence that seals and seabirds could take substantial fractions of salmon populations in the marine environment, it does not necessarily follow that seal and seabird predation is the cause of the long-term decline in North American salmon returns. Even under normal circumstances (i.e. no population decline), the great majority of salmon that enter the sea die there. Therefore, for seal and seabird predation to have caused the decline, the rate of predation (percent of population removed) must have increased.

An increase in predation rate could occur as a result of rising predator numbers. Amiro (1998) showed that increasing harp seal populations in the Northwest Atlantic are statistically related to the decline in Atlantic salmon returns. Harp seals are the main predator among those considered in this paper, accounting for one half of the 6.2 million $t$ of prey consumed by seals and seabirds in
eastern Canadian waters. Harp seal populations have been increasing at a rate of $4 \%$ annually (although they appear to have leveled off since 1996, Stenson et al. 1999). Populations of hooded seals have been increasing at $4.8 \%$, and grey seal numbers have been rising at $12.6 \%$ at Sable Island and $6.8 \%$ in the Gulf of St. Lawrence (Hammill and Stenson 1997). Population levels of harbour seals are poorly known but appear to be rising. Numbers of murres and gannets are rising in eastern North America (Chardine et al. 1999). Population trends of seabirds which visit eastern Canadian waters as nonbreeding migrants (fulmars, shearwaters) are unknown.

This study has emphasized what is plausible, because our present knowledge is insufficient to determine what is real. Its implicit assumption is that if there is more predation there will be fewer prey. However, the relation between marine predators and their prey is complex with many potential cause-and-effect chains, and predator increases do not necessarily lead to lower prey populations (Fiscus 1980, Gulland 1987, Butterworth 1992, Smith 1995).

This paper has examined the potential role of birds and seals as salmon predators, but has not considered cetaceans. Diets of most odontocete cetacean species have not been examined in the northwest Atlantic, but studies in the northeast Atlantic have reported that salmon are present in the diets of belugas and bottlenose dolphins (Anon. 1999c). Fontaine et al. (1994) found four salmonid otoliths in one harbour porpoise stomach from the Gulf of St. Lawrence system, but the otoliths were too eroded to identify the species. Size ranges of post-smolt salmon overlap the prey size distributions of most odontocete cetaceans (Anon. 1999c). Bioenergetics models estimate that cetaceans consume 1.9 million $t$ annually in the Northeast Shelf of the United States and 6.3 million $t$ annually in waters around Iceland (Kenney et al. 1997, Sigurjonsson and Vikingsson 1998). Estimates of harvest by cetaceans in eastern Canadian waters are unavailable, but are presumably substantial given the large harvests estimated for nearby waters. These points collectively suggest that cetaceans in eastern Canadian waters could be significant predators of Atlantic salmon.

## FUTURE RESEARCH

Although the major problem with North American salmon populations appears to lie in the sea, most salmon research is directed toward fresh water. Conventional stomach analysis of seal and seabird predation in the open sea appears to have little potential to clarify the impact of marine predation on salmon because salmon predation is such a rare event. However, there are several lines of investigation that may increase basic understanding of the marine biology of Atlantic salmon, and which may ultimately assist in elucidating the predator-prey relations of salmon at sea. These include:
a) Fishermen's knowledge of post-smolts - Anecdotal reports from fishermen prompted Dutil and Coutu's (1988) work in the northwestern Gulf of St. Lawrence, which identified a gathering area for post-smolts. Fishermen's knowledge could be
systematically polled to locate other areas where post-smolts are commonly bycaught.
b) Gannets as samplers - Samples obtained from gannets may be useful indicators of timing and routes of post-smolt migrations, and provide weights and measures and specimens for scale and otolith investigations (Friedland and Haas 1996). Gannets breed in six colonies in the Gulf of St. Lawrence and eastern and northeastern Newfoundland, and their diets can be readily and non-destructively sampled. Sampling from gannets is likely to produce data at lower cost than directed research cruises.
c) Research fishing - Surveys using surface gillnets (Dutil and Coutu 1988, Reddin and Short 1991) or trawls could be conducted to locate concentrations of post-smolts and obtain samples.
d) Salmon scarring - Scars attributed to seals are commonly found on salmon returning to rivers (Baum 1997; D. Sutherland and D. Moore, DFO, pers. comm.) Such scars could be investigated to determine whether the predator can be identified from the pattern of scarring. Scales from the scar area could be examined to determine if the age of scar can be determined from scale patterns. Scarring rates could be monitored to determine regional and temporal patterns.
e) Predator diet studies - There may be scope for better identification of salmon remains by those involved in predator diet analysis. Reference salmon otoliths should be provided where needed, and the utility of identifying and reporting salmon remains should be emphasized.
f) Scale and otolith patterns - Scales and otoliths can provide valuable insights into marine history (Friedland and Haas 1996, Friedland et al. 1996); such investigations should continue with emphasis on integrating findings with other sources of information on salmon's marine life.
g) Studies in estuaries - Predation by seals and birds (notably cormorants and gulls) on outgoing smolts, and by seals on returning adults, has potential to impact salmon populations. Unlike the high seas where adequate samples are impractical, this predation is localized, meaning that focused efforts would have a reasonable chance of elucidating predator impacts.

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Table 1
Recoveries of tagged post-smolts from New England, Maritime, and Quebec rivers. Data from Ritter 1989. Records with unknown recovery dates are excluded.

| Home region | Recovery Region | Month of recovery |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Jun | Jul | Aug | Sep | Oct | Total |
| Maine, Saint John R. | Home river mouth |  |  |  |  |  | 0 |
|  | Gulf of Maine, Fundy, Atlantic Nova Scotia | 45 | 145 | 87 | 5 | 1 | 283 |
|  | Gulf of St. Lawrence |  | 2 |  |  |  | 2 |
|  | Atlantic coast, Newfoundland | 3 | 11 | 4 | 1 |  | 19 |
|  | Southern Labrador |  | 1 |  | 1 |  | 2 |
|  | Total | 48 | 159 | 91 | 7 | 1 | 306 |
| Southwest Nova Scotia | Home river mouth | 39 | 3 |  |  |  | 42 |
|  | Gulf of Maine, Fundy, Atlantic Nova Scotia | 18 | 7 | 1 | 1 |  | 27 |
|  | Gulf of St. Lawrence |  | 2 |  |  |  | 2 |
|  | Atlantic coast, Newfoundland |  | 4 |  |  |  | 4 |
|  | Northern Labrador |  |  | 1 | 1 |  | 2 |
|  | Total | 57 | 16 | 2 | 2 | 0 | 77 |
| Gulf of St. Lawrence | Home river mouth | 17 | 1 | 1 |  |  | 19 |
|  | Gulf of Maine, Fundy, Atlantic Nova Scotia | 1 |  | 1 |  |  | 2 |
|  | Gulf of St. Lawrence | 2 | 3 | 3 | 2 | 1 | 11 |
|  | Atlantic coast, Newfoundland |  | $2^{\text {a }}$ |  |  |  | 2 |
|  | Southern Labrador |  |  | 1 | 2 |  | 3 |
|  | Total | 20 | 6 | 6 | 4 | 1 | 37 |

[^0]Table 2
Return rates (percent) of wild smolts to 1 sea winter adults in North American rivers.

| Smolt year | Quebec |  |  | New | Newfoundland |  |  |  |  |  | Mean |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Bec- | de la Trinité | SaintJean | Brunswick Catamaran | Highlands | Campbellton | Western Arm Brook | Northeast Trepassy | Rocky River | Conne River |  |
| Return rates ${ }^{\text {ab }}$ |  |  |  |  |  |  |  |  |  |  |  |
| 1977 | (0.81) | (1.21) | (0.25) | (5.80) | (0.90) | (3.16) | 3.10 | (3.82) | (1.94) | (3.66) | 2.47 |
| 1978 | (3.14) | (4.68) | (0.97) | (22.47) | (3.49) | (12.22) | 12.00 | (14.80) | (7.50) | (14.16) | 9.54 |
| 1979 | (1.47) | (2.18) | (0.45) | (10.49) | (1.63) | (5.70) | 5.60 | (6.90) | (3.50) | (6.61) | 4.45 |
| 1980 | (0.78) | (1.17) | (0.24) | (5.62) | (0.87) | (3.05) | 3.00 | (3.70) | (1.88) | (3.54) | 2.39 |
| 1981 | (0.86) | (1.29) | (0.27) | (6.18) | (0.96) | (3.36) | 3.30 | (4.07) | (2.06) | (3.89) | 2.62 |
| 1982 | (2.38) | (3.55) | (0.74) | (17.04) | (2.65) | (9.27) | 9.10 | (11.22) | (5.69) | (10.74) | 7.24 |
| 1983 | (0.58) | (0.86) | (0.18) | (4.12) | (0.64) | (2.24) | 2.20 | (2.71) | (1.38) | (2.60) | 1.75 |
| 1984 | (0.75) | 1.61 | (0.25) | (5.91) | (1.00) | (3.51) | 2.20 | (3.46) | (1.97) | (3.34) | 2.40 |
| 1985 | (1.25) | 2.43 | (0.41) | (9.83) | (1.67) | (5.84) | 3.90 | (5.76) | (3.28) | (5.55) | 3.99 |
| 1986 | (1.33) | 1.40 | (0.43) | (10.17) | (1.70) | (5.94) | 2.50 | 8.10 | (3.40) | (5.73) | 4.07 |
| 1987 | (1.66) | 2.19 | (0.55) | (13.31) | (2.26) | (7.90) | 2.10 | 6.90 | (4.44) | 10.20 | 5.15 |
| 1988 | 1.61 | 3.67 | (0.46) | (10.83) | (1.88) | (6.57) | 3.00 | 3.70 | (3.62) | 7.60 | 4.29 |
| 1989 | 1.68 | 2.57 | 0.55 | (11.20) | (1.91) | (6.67) | 3.80 | 4.20 | (3.74) | 7.30 | 4.36 |
| 1990 | 1.69 | 2.69 | 0.45 | 10.30 | (1.59) | (5.57) | 2.20 | 5.20 | 2.50 | 4.20 | 3.64 |
| 1991 | 1.17 | 1.56 | 0.49 | 11.10 | (1.47) | (5.15) | 3.60 | 2.60 | 3.10 | 3.40 | 3.36 |
| 1992 | 1.27 | 0.81 | 0.40 | 5.00 | (1.37) | (4.80) | 5.30 | 4.70 | 3.70 | 4.00 | 3.14 |
| 1993 | 0.92 | 0.67 | 0.35 | 13.60 | 1.45 | 9.05 | 6.80 | 5.40 | 3.10 | 2.70 | 4.40 |
| 1994 | 1.17 | 0.62 | 0.33 | 13.50 | 1.64 | 7.29 | 8.90 | 8.50 | 3.90 | 5.80 | 5.16 |
| 1995 | 1.40 | 0.92 | 0.57 | 8.50 | 1.64 | 8.08 | 8.10 | 9.20 | 4.60 | 7.20 | 5.02 |
| 1996 | (0.94) | 0.65 | 0.29 | 9.90 | 3.21 | 3.38 | 3.50 | 2.90 | 3.10 | 3.40 | 3.13 |
| 1997 | (1.10) | 1.66 | (0.38) | 5.50 | 1.40 | 5.30 | 7.50 | 5.00 | 2.40 | 2.90 | 3.31 |
| Correction factors for missing values ${ }^{\text {c }}$ |  |  |  |  |  |  |  |  |  |  |  |
| 1977-1983 | 0.26 | 0.39 | 0.08 | 1.87 | 0.29 | 1.02 |  | 1.23 | 0.63 | 1.18 |  |
| 1984-1985 | 0.40 |  | 0.13 | 3.10 | 0.53 | 1.84 |  | 1.82 | 1.04 | 1.75 |  |
| 1986 | 0.33 |  | 0.11 | 2.54 | 0.42 | 1.48 |  |  | 0.85 | 1.43 |  |
| 1987 | 0.31 |  | 0.10 | 2.49 | 0.42 | 1.48 |  |  | 0.83 |  |  |
| 1988 |  |  | 0.12 | 2.77 | 0.48 | 1.68 |  |  | 0.92 |  |  |
| 1989 |  |  |  | 3.34 | 0.57 | 1.99 |  |  | 1.12 |  |  |
| 1990-1992 |  |  |  |  | 0.44 | 1.52 |  |  |  |  |  |
| 1996 | 0.28 |  |  |  |  |  |  |  |  |  |  |
| 1997 | 0.28 |  | 0.10 |  |  |  |  |  |  |  |  |
| 1SW returns as a proportion of total returns ${ }^{\text {d }}$ |  |  |  |  |  |  |  |  |  |  |  |
|  | 0.54 | 0.55 | 0.24 | 0.72 | 0.93 | 0.93 | 0.93 | 0.93 | 0.93 | 0.93 | 0.74 |
| Ratio of river 1SW return proportion to North American 1SW return proportion |  |  |  |  |  |  |  |  |  |  |  |
|  | 0.73 | 0.73 | 0.33 | 0.96 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 |  |
| Return rates weighted for proportion returning as 1SW ${ }^{\text {e }}$ |  |  |  |  |  |  |  |  |  |  |  |
| 1977 | 1.11 | 1.65 | 0.77 | 6.03 | 0.72 | 2.52 | 2.48 | 3.05 | 1.55 | 2.92 | 2.28 |
| 1978 | 4.28 | 6.37 | 3.00 | 23.33 | 2.79 | 9.76 | 9.59 | 11.82 | 5.99 | 11.31 | 8.82 |
| 1979 | 2.00 | 2.97 | 1.40 | 10.89 | 1.30 | 4.56 | 4.47 | 5.52 | 2.80 | 5.28 | 4.12 |
| 1980 | 1.07 | 1.59 | 0.75 | 5.83 | 0.70 | 2.44 | 2.40 | 2.95 | 1.50 | 2.83 | 2.21 |
| 1981 | 1.18 | 1.75 | 0.82 | 6.41 | 0.77 | 2.68 | 2.64 | 3.25 | 1.65 | 3.11 | 2.43 |
| 1982 | 3.25 | 4.83 | 2.27 | 17.69 | 2.11 | 7.40 | 7.27 | 8.96 | 4.54 | 8.58 | 6.69 |
| 1983 | 0.78 | 1.17 | 0.55 | 4.28 | 0.51 | 1.79 | 1.76 | 2.17 | 1.10 | 2.07 | 1.62 |
| 1984 | 1.03 | 2.19 | 0.76 | 6.14 | 0.80 | 2.80 | 1.76 | 2.77 | 1.58 | 2.67 | 2.25 |
| 1985 | 1.71 | 3.31 | 1.27 | 10.21 | 1.33 | 4.66 | 3.12 | 4.60 | 2.62 | 4.44 | 3.73 |
| 1986 | 1.81 | 1.91 | 1.33 | 10.56 | 1.36 | 4.75 | 2.00 | 6.47 | 2.71 | 4.58 | 3.75 |
| 1987 | 2.26 | 2.98 | 1.69 | 13.82 | 1.80 | 6.31 | 1.68 | 5.51 | 3.55 | 8.15 | 4.78 |
| 1988 | 2.20 | 4.99 | 1.41 | 11.25 | 1.50 | 5.24 | 2.40 | 2.96 | 2.89 | 6.07 | 4.09 |
| 1989 | 2.29 | 3.50 | 1.70 | 11.63 | 1.52 | 5.33 | 3.04 | 3.36 | 2.99 | 5.83 | 4.12 |
| 1990 | 2.31 | 3.66 | 1.37 | 10.69 | 1.27 | 4.45 | 1.76 | 4.15 | 2.00 | 3.36 | 3.50 |
| 1991 | 1.60 | 2.12 | 1.51 | 11.52 | 1.17 | 4.11 | 2.88 | 2.08 | 2.48 | 2.72 | 3.22 |
| 1992 | 1.74 | 1.10 | 1.23 | 5.19 | 1.09 | 3.83 | 4.23 | 3.75 | 2.96 | 3.20 | 2.83 |
| 1993 | 1.25 | 0.92 | 1.06 | 14.12 | 1.16 | 7.23 | 5.43 | 4.31 | 2.48 | 2.16 | 4.01 |
| 1994 | 1.59 | 0.85 | 1.02 | 14.02 | 1.31 | 5.82 | 7.11 | 6.79 | 3.12 | 4.63 | 4.63 |
| 1995 | 1.91 | 1.26 | 1.75 | 8.82 | 1.31 | 6.45 | 6.47 | 7.35 | 3.67 | 5.75 | 4.47 |
| 1996 | 1.28 | 0.88 | 0.89 | 10.28 | 2.57 | 2.70 | 2.80 | 2.32 | 2.48 | 2.72 | 2.89 |
| 1997 | 1.50 | 2.25 | 1.16 | 5.71 | 1.12 | 4.23 | 5.99 | 3.99 | 1.92 | 2.32 | 3.02 |

Table 2 (continued)
${ }^{\text {a }}$ Data from Anon. 1999a, R.A. Cunjak in Chaput et al. 1999, and O'Connell et al. 1998.
${ }^{\mathrm{b}}$ Unbracketed return rates are directly measured. Bracketed rates are estimated as the product of correction factors and the mean of available return rates in the same year. For example, the return rate for the Saint-Jean in 1984 is calculated as $0.13^{*}(1.62+2.2) / 2=0.25$
${ }^{\circ}$ Correction factors are the mean of directly measured return rates for the site, divided by the mean of return rates for other sites for the same years. For example, the mean return rate for the Saint-Jean for 1989-1996 is $0.43 \%$. The mean return rate for Trinité and Western Arm Brook for these years is $3.29 \%$. The correction factor is $0.43 / 3.29=0.13$.
${ }^{\text {d D Data for Quebec for 1984-1995 (Caron 1996a and b); data for New Brunswick for 1977-1996 (Chaput et al. 1999); }}$ data for Newfoundland (overall mean) for 1984-1996 (O'Connell et al. 1998); North American mean for 1971-1995 (Anon. 1996).
${ }^{9}$ Return rate divided by ratio of river 1SW return proportion to North American 1SW return proportion

Table 3
Numbers of Alantic salmon returning after 1 sea winter, estimated number of smolts leaving North American rivers, and numbers of 1SW salmon in the sea prior to fishing mortality.

| Smolt year (Yr) | North American 1SW returns in $\mathrm{Yr}+1^{\mathrm{a}}$ | Return rate (percent), wild smolts to $1 \mathrm{SW}^{\text {b }}$ | North American smolt run in $Y$ | North American pre-fishery maturing 1SW in $\mathrm{Yr}+1^{\mathrm{a}}$ | North American pre-fishery non-maturing 1SW in $\mathrm{Yr}+1^{\mathrm{a}}$ | North American pre-fishery total 1SW in $\mathrm{Yr}+1$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1977 | 253,529 | 2.3 | 11,123,726 | 408,520 | 330,077 | 738,597 |
| 1978 | 348,313 | 8.8 | 3,947,960 | 587,390 | 730,725 | 1,318,115 |
| 1979 | 455,533 | 4.1 | 11,064,102 | 838,092 | 639,192 | 1,477,284 |
| 1980 | 560,048 | 2.2 | 25,391,499 | 908,837 | 605,935 | 1,514,772 |
| 1981 | 467,402 | 2.4 | 19,264,643 | 761,207 | 503,481 | 1,264,688 |
| 1982 | 294,371 | 6.7 | 4,399,851 | 513,115 | 286,898 | 800,013 |
| 1983 | 336,119 | 1.6 | 20,780,439 | 512,873 | 296,450 | 809,323 |
| 1984 | 386,842 | 2.2 | 17,202,365 | 634,337 | 468,776 | 1,103,113 |
| 1985 | 506,947 | 3.7 | 13,605,732 | 812,048 | 505,066 | 1,317,114 |
| 1986 | 495,765 | 3.7 | 13,232,556 | 848,239 | 462,953 | 1,311,192 |
| 1987 | 559,399 | 4.8 | 11,713,300 | 823,410 | 370,526 | 1,193,936 |
| 1988 | 341,626 | 4.1 | 8,352,764 | 567,807 | 293,057 | 860,864 |
| 1989 | 399,743 | 4.1 | 9,708,190 | 549,267 | 256,969 | 806,236 |
| 1990 | 273,818 | 3.5 | 7,819,152 | 401,895 | 299,086 | 700,981 |
| 1991 | 475,802 | 3.2 | 14,783,255 | 506,855 | 179,755 | 686,610 |
| 1992 | 426,144 | 2.8 | 15,045,579 | 447,931 | 137,134 | 585,065 |
| 1993 | 312,227 | 4.0 | 7,782,740 | 325,400 | 161,214 | 486,614 |
| 1994 | 326,148 | 4.6 | 7,051,523 | 338,165 | 156,490 | 494,655 |
| 1995 | 458,860 | 4.5 | 10,256,088 | 471,416 | 126,588 | 598,004 |
| 1996 | 306,480 | 2.9 | 10,605,458 | 319,065 | 97,899 | 416,964 |
| $1997{ }^{\text {c }}$ | 349,451 | 3.0 | 11,575,497 | 412,480 |  |  |
| Mean 1977-1996 | 399,256 | 4 | 12,156,546 | 578,793 | 345,414 | 924,207 |
| Mean 1990-1996 | 368,497 | 4 | 10,477,685 | 401,532 | 165,452 | 566,985 |

${ }^{2}$ From Anon. 1999a
${ }^{\text {b }}$ From Table 2
${ }^{\text {c }}$ Returns for Labrador are estimated from returns from other regions, using the ratio of Labrador returns:returns for other regions averaged for 1978-1996 (0.20)

Table 4
Fork length, weight, and number of North American Atlantic salmon alive from river exit to sea age 1 year, by month.

| Smolt Daily | Date |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| year mortality | Jun | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May |
| (Yr) $\begin{gathered}\text { per g } \\ \left(\mathrm{M}_{\mathrm{u}}\right)\end{gathered}$ | 1 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Individual measures |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Fork length (cm) | 13.8 | 14.8 | 18.6 | 25.1 | 32.9 | 38.7 | 42.0 | 43.5 | 44.1 | 44.4 | 44.7 | 45.6 | 47.4 |
| Weight (g) | 21 | 36 | 93 | 211 | 412 | 653 | 872 | 1007 | 1079 | 1112 | 1130 | 1165 | 1245 |

$\frac{\text { Numbers }}{0 \% \text { mortality at river exit }}$
$1977 \quad 0.0441$

| 1977 | 0.0441 | $11,123,726$ |
| ---: | ---: | ---: |
| 1978 | 0.0179 | $3,947,960$ |
| 1979 | 0.0328 | $11,064,102$ |
| 1980 | 0.0459 | $25,391,499$ |
| 1981 | 0.0443 | $19,264,643$ |
| 1982 | 0.0277 | $4,399,851$ |
| 1983 | 0.0528 | $20,780,439$ |
| 1984 | 0.0446 | $17,202,365$ |
| 1985 | 0.0381 | $13,605,732$ |
| 1986 | 0.0376 | $13,232,556$ |
| 1987 | 0.0372 | $11,713,300$ |
| 1988 | 0.0370 | $8,352,764$ |
| 1989 | 0.0405 | $9,708,190$ |
| 1990 | 0.0392 | $7,819,152$ |
| 1991 | 0.0500 | $14,783,255$ |
| 1992 | 0.0528 | $15,045,579$ |
| 1993 | 0.0451 | $7,782,740$ |
| 1994 | 0.0432 | $7,051,523$ |
| 1995 | 0.0463 | $10,256,088$ |
| 1996 | 0.0527 | $10,605,458$ |
| Mean $^{\text {a }}$ | 0.0419 | $12,156,546$ |
| Mean $^{\text {b }}$ | 0.0475 | $10,477,685$ |

$20 \%$ mortality at river exi

| 1977 | 0.0405 | $11,123,726$ |
| :--- | :--- | :--- |


| 1977 | 0.0405 | $11,123,726$ |
| ---: | ---: | ---: |
| 1978 | 0.0142 | $3,947,960$ |


| 1978 | 0.0142 | $3,947,960$ | 2, |
| ---: | ---: | ---: | ---: |
| 1979 | 0.0291 | $11,064,102$ | 7, |
| 1980 | 0.0422 | $25,391,499$ | 16,35 |


| 1981 | 0.0407 | $19,364,643$ | 12, |
| ---: | ---: | ---: | ---: |
| 1982 | 0.0241 | $4,399,851$ | 3, |
| 1983 | 0.0492 | $20,780,439$ | 12 |
| 1984 | 0.0410 | $17,202,365$ | 11, |


| 1984 | 0.0410 | $17,202,365$ | 11,1 |
| ---: | ---: | ---: | ---: |
| 1985 | 0.0345 | $13,605,732$ | 9,1 |
| 1986 | 0.0340 | $13,232,556$ | 8, |
| 1987 | 0.0335 | $11,713,300$ | 7, |
| 1988 | 0.0333 | $8,352,764$ | 5, |
| 1989 | 0.0369 | $9,708,190$ | 6,4 |


| 8,867,341 | 6,025,172 | 4,445,067 | 3,490,841 | 2,868,247 | 2,393,728 | 2,031,686 | 1,724,116 | 1,466,577 | 1,268,384 | 1,081,166 | 928,331 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 3,601,975 | 3,080,669 | 2,723,991 | 2,470,287 | 2,281,563 | 2,120,593 | 1,984,472 | 1,856,964 | 1,739,315 | 1,640,094 | 1,537,478 | 1,445,543 |
| 9,350,094 | 7,018,004 | 5,599,398 | 4,679,739 | 4,044,640 | 3,536,436 | 3,131,045 | 2,771,784 | 2,458,062 | 2,206,875 | 1,960,118 | 1,750,407 |
| 20,060,606 | 13,424,367 | 9,785,595 | 7,611,940 | 6,206,022 | 5,142,454 | 4,336,510 | 3,656,247 | 3,090,293 | 2,657,394 | 2,250,915 | 1,921,127 |
| 15,342,305 | 10,407,869 | 7,668,597 | 6,016,265 | 4,939,183 | 4,118,922 | 3,493,544 | 2,962,626 | 2,518,373 | 2,176,712 | 1,854,179 | 1,591,050 |
| 3,815,461 | 2,992,617 | 2,471,822 | 2,123,468 | 1,876,795 | 1,675,115 | 1,511,041 | 1,362,895 | 1,231,105 | 1,123,722 | 1,016,388 | 923,532 |
| 15,842,798 | 9,976,950 | 6,933,061 | 5,191,993 | 4,104,306 | 3,305,592 | 2,716,582 | 2,232,083 | 1,839,198 | 1,545,867 | 1,276,943 | 1,064,051 |
| 13,677,136 | 9,251,979 | 6,801,728 | 5,326,722 | 4,366,787 | 3,636,754 | 3,080,874 | 2,609,524 | 2,215,587 | 1,912,965 | 1,627,603 | 1,395,067 |
| 11,186,651 | 8,012,659 | 6,161,837 | 5,001,299 | 4,220,955 | 3,610,659 | 3,133,910 | 2,719,721 | 2,365,104 | 2,086,413 | 1,817,634 | 1,593,488 |
| 10,907,329 | 7,846,285 | 6,054,365 | 4,927,312 | 4,167,620 | 3,572,223 | 3,106,216 | 2,700,621 | 2,352,729 | 2,078,855 | 1,814,274 | 1,593,244 |
| 9,677,990 | 6,990,183 | 5,410,989 | 4,414,863 | 3,741,872 | 3,213,379 | 2,798,988 | 2,437,696 | 2,127,276 | 1,882,507 | 1,645,665 | 1,447,486 |
| 6,908,834 | 4,999,274 | 3,875,464 | 3,165,657 | 2,685,601 | 2,308,280 | 2,012,179 | 1,753,817 | 1,531,663 | 1,356,363 | 1,186,618 | 1,044,477 |
| 7,885,135 | 5,531,454 | 4,184,586 | 3,352,493 | 2,799,607 | 2,371,587 | 2,040,328 | 1,755,073 | 1,512,981 | 1,324,295 | 1,143,805 | 994,550 |
| 6,391,743 | 4,533,180 | 3,459,056 | 2,790,267 | 2,343,103 | 1,995,070 | 1,724,393 | 1,490,221 | 1,290,563 | 1,134,270 | 984,120 | 859,404 |
| 11,437,009 | 7,384,621 | 5,233,535 | 3,980,972 | 3,187,207 | 2,597,153 | 2,157,125 | 1,791,314 | 1,491,531 | 1,265,471 | 1,056,175 | 888,804 |
| 11,469,398 | 7,221,527 | 5,017,591 | 3,757,126 | 2,969,765 | 2,391,637 | 1,965,332 | 1,614,696 | 1,330,382 | 1,118,126 | 923,545 | 769,518 |
| 6,173,254 | 4,159,162 | 3,047,999 | 2,381,018 | 1,947,943 | 1,619,236 | 1,369,394 | 1,157,906 | 981,452 | 846,118 | 718,704 | 615,045 |
| 5,647,149 | 3,867,407 | 2,870,888 | 2,265,705 | 1,869,070 | 1,565,604 | 1,333,253 | 1,135,202 | 968,815 | 840,368 | 718,659 | 618,984 |
| 8,086,595 | 5,392,988 | 3,920,607 | 3,043,212 | 2,476,822 | 2,049,069 | 1,725,424 | 1,452,646 | 1,226,032 | 1,052,930 | 890,613 | 759,101 |
| 8,092,113 | 5,103,093 | 3,550,074 | 2,660,879 | 2,104,935 | 1,696,413 | 1,394,961 | 1,146,851 | 945,537 | 795,151 | 657,203 | 547,935 |
| 9,801,205 | 6,789,727 | 5,085,928 | 4,042,713 | 3,354,501 | 2,824,983 | 2,417,469 | 2,068,416 | 1,773,746 | 1,545,227 | 1,327,713 | 1,148,752 |
| 8,210,954 | 5,419,144 | 3,907,435 | 3,013,282 | 2,439,502 | 2,008,373 | 1,683,693 | 1,411,250 | 1,185,907 | 1,014,490 | 854,410 | 725,257 |
| 7,227,402 | 5,069,475 | 3,834,753 | 3,072,005 | 2,565,228 | 2,172,926 | 1,869,326 | 1,607,900 | 1,386,044 | 1,213,136 | 1,047,747 | 910,985 |
| 2,935,827 | 2,592,038 | 2,350,006 | 2,173,925 | 2,040,555 | 1,925,017 | 1,825,917 | 1,731,828 | 1,643,840 | 1,568,691 | 1,489,991 | 1,418,570 |
| 7,620,892 | 5,904,865 | 4,830,639 | 4,118,308 | 3,617,392 | 3,210,281 | 2,880,882 | 2,584,999 | 2,323,134 | 2,110,797 | 1,899,577 | 1,717,746 |
| 16,350,607 | 11,295,103 | 8,442,100 | 6,698,730 | 5,550,460 | 4,668,180 | 3,990,033 | 3,409,860 | 2,920,660 | 2,541,702 | 2,181,392 | 1,885,281 |
| 12,504,906 | 8,757,057 | 6,615,751 | 5,294,490 | 4,417,442 | 3,739,045 | 3,214,418 | 2,762,981 | 2,380,133 | 2,081,947 | 1,796,909 | 1,561,363 |
| 3,109,831 | 2,517,952 | 2,132,458 | 1,868,714 | 1,678,543 | 1,520,624 | 1,390,312 | 1,271,053 | 1,163,527 | 1,074,799 | 984,995 | 906,300 |
| 12,912,839 | 8,394,488 | 5,981,199 | 4,569,106 | 3,670,755 | 3,000,727 | 2,499,534 | 2,081,668 | 1,738,241 | 1,478,566 | 1,237,502 | 1,044,197 |
| 11,147,693 | 7,784,505 | 5,867,897 | 4,687,671 | 3,905,509 | 3,301,347 | 2,834,720 | 2,433,674 | 2,093,968 | 1,829,682 | 1,577,332 | 1,369,036 |
| 9,117,797 | 6,741,757 | 5,315,859 | 4,401,289 | 3,775,083 | 3,277,658 | 2,883,518 | 2,536,445 | 2,235,278 | 1,995,579 | 1,761,494 | 1,563,755 |
| 8,890,133 | 6,601,771 | 5,223,143 | 4,336,179 | 3,727,382 | 3,242,767 | 2,858,037 | 2,518,632 | 2,223,583 | 1,988,350 | 1,758,237 | 1,563,515 |
| 7,888,147 | 5,881,457 | 4,668,097 | 3,885,209 | 3,346,606 | 2,917,019 | 2,575,356 | 2,273,425 | 2,010,505 | 1,800,550 | 1,594,837 | 1,420,477 |
| 5,631,117 | 4,206,330 | 3,343,389 | 2,785,871 | 2,401,913 | 2,095,394 | 1,851,410 | 1,635,631 | 1,447,586 | 1,297,312 | 1,149,968 | 1,024,988 |
| 6,426,862 | 4,654,100 | 3,610,071 | 2,950,292 | 2,503,876 | 2,152,862 | 1,877,311 | 1,636,802 | 1,429,931 | 1,266,641 | 1,108,477 | 975,992 |
| 5,209,657 | 3,814,164 | 2,984,152 | 2,455,516 | 2,095,594 | 1,811,070 | 1,586,618 | 1,389,798 | 1,219,721 | 1,084,888 | 953,724 | 843,368 |
| 9,321,854 | 6,213,333 | 4,515,006 | 3,503,372 | 2,850,532 | 2,357,625 | 1,984,776 | 1,670,602 | 1,409,658 | 1,210,378 | 1,023,553 | 872,220 |
| 9,348,253 | 6,076,107 | 4,328,710 | 3,306,381 | 2,656,059 | 2,171,063 | 1,808,307 | 1,505,885 | 1,257,354 | 1,069,447 | 895,020 | 755,159 |
| 5,031,576 | 3,499,470 | 2,629,530 | 2,095,366 | 1,742,176 | 1,469,899 | 1,259,983 | 1,079,878 | 927,578 | 809,281 | 696,506 | 603,569 |
| 4,602,768 | 3,253,990 | 2,476,735 | 1,993,887 | 1,671,634 | 1,421,213 | 1,226,730 | 1,058,703 | 915,635 | 803,782 | 696,462 | 607,435 |
| 6,591,064 | 4,537,596 | 3,382,335 | 2,678,116 | 2,215,187 | 1,860,089 | 1,587,567 | 1,354,755 | 1,158,732 | 1,007,090 | 863,105 | 744,937 |
| 6,595,561 | 4,293,682 | 3,062,673 | 2,341,652 | 1,882,584 | 1,539,958 | 1,283,507 | 1,069,567 | 893,635 | 760,534 | 636,904 | 537,712 |
| 7,988,575 | 5,712,796 | 4,387,665 | 3,557,706 | 3,000,154 | 2,564,443 | 2,224,319 | 1,929,030 | 1,676,382 | 1,477,954 | 1,286,705 | 1,127,317 |
| 6,692,424 | 4,559,604 | 3,370,971 | 2,651,777 | 2,181,810 | 1,823,147 | 1,549,170 | 1,316,149 | 1,120,810 | 970,324 | 828,020 | 711,724 |


| Smolt <br> year <br> (Yr) | Daily mortality per g $\left(\mathrm{M}_{\mathrm{u}}\right)$ | Date |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Jun | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May |
|  |  | 1 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| 40\% mortality at river exit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1977 | 0.0358 | 11,123,726 | 5,552,467 | 4,057,575 | 3,169,938 | 2,605,351 | 2,221,360 | 1,918,086 | 1,679,043 | 1,469,593 | 1,288,745 | 1,145,479 | 1,006,214 | 889,130 |
| 1978 | 0.0095 | 3,947,960 | 2,255,455 | 2,074,650 | 1,942,595 | 1,843,694 | 1,767,019 | 1,699,252 | 1,640,053 | 1,582,860 | 1,528,444 | 1,481,204 | 1,430,927 | 1,384,538 |
| 1979 | 0.0245 | 11,064,102 | 5,854,767 | 4,726,215 | 3,993,172 | 3,492,715 | 3,132,481 | 2,833,780 | 2,587,630 | 2,362,644 | 2,160,052 | 1,993,077 | 1,824,277 | 1,676,537 |
| 1980 | 0.0376 | 25,391,499 | 12,561,389 | 9,040,526 | 6,978,528 | 5,681,158 | 4,806,422 | 4,120,698 | 3,583,878 | 3,116,552 | 2,715,632 | 2,399,950 | 2,094,921 | 1,840,052 |
| 1981 | 0.0360 | 19,264,643 | 9,606,921 | 7,009,091 | 5,468,806 | 4,490,229 | 3,825,284 | 3,300,531 | 2,887,215 | 2,525,316 | 2,213,050 | 1,965,836 | 1,725,679 | 1,523,905 |
| 1982 | 0.0194 | 4,399,851 | 2,389,134 | 2,015,352 | 1,762,763 | 1,584,847 | 1,453,534 | 1,342,286 | 1,248,789 | 1,161,720 | 1,081,849 | 1,014,857 | 945,950 | 884,557 |
| 1983 | 0.0445 | 20,780,439 | 9,920,316 | 6,718,893 | 4,944,264 | 3,875,034 | 3,178,691 | 2,648,803 | 2,245,100 | 1,902,608 | 1,616,218 | 1,396,106 | 1,188,447 | 1,019,146 |
| 1984 | 0.0363 | 17,202,365 | 8,564,239 | 6,230,667 | 4,850,604 | 3,975,589 | 3,381,976 | 2,914,166 | 2,546,167 | 2,224,335 | 1,946,974 | 1,727,640 | 1,514,806 | 1,336,192 |
| 1985 | 0.0298 | 13,605,732 | 7,004,767 | 5,396,058 | 4,394,270 | 3,732,710 | 3,269,033 | 2,893,256 | 2,589,997 | 2,318,266 | 2,078,364 | 1,884,285 | 1,691,667 | 1,526,240 |
| 1986 | 0.0293 | 13,232,556 | 6,829,864 | 5,284,014 | 4,317,628 | 3,677,490 | 3,227,726 | 2,862,457 | 2,567,111 | 2,301,985 | 2,067,489 | 1,877,459 | 1,688,540 | 1,526,006 |
| 1987 | 0.0288 | 11,713,300 | 6,060,086 | 4,707,480 | 3,858,809 | 3,295,025 | 2,897,994 | 2,574,912 | 2,313,204 | 2,077,871 | 1,869,370 | 1,700,133 | 1,531,617 | 1,386,399 |
| 1988 | 0.0286 | 8,352,764 | 4,326,118 | 3,366,719 | 2,763,760 | 2,362,682 | 2,079,937 | 1,849,647 | 1,662,951 | 1,494,938 | 1,345,967 | 1,224,961 | 1,104,382 | 1,000,398 |
| 1989 | 0.0322 | 9,708,190 | 4,937,451 | 3,725,111 | 2,984,208 | 2,502,127 | 2,168,232 | 1,900,376 | 1,686,215 | 1,496,008 | 1,329,551 | 1,195,999 | 1,064,537 | 952,578 |
| 1990 | 0.0309 | 7,819,152 | 4,002,330 | 3,052,832 | 2,466,802 | 2,082,510 | 1,814,680 | 1,598,668 | 1,425,112 | 1,270,251 | 1,134,098 | 1,024,383 | 915,918 | 823,136 |
| 1991 | 0.0417 | 14,783,255 | 7,161,535 | 4,973,111 | 3,732,259 | 2,971,191 | 2,468,419 | 2,081,123 | 1,782,741 | 1,526,901 | 1,310,701 | 1,142,875 | 982,979 | 851,295 |
| 1992 | 0.0445 | 15,045,579 | 7,181,815 | 4,863,276 | 3,578,260 | 2,804,125 | 2,300,015 | 1,916,442 | 1,624,235 | 1,376,352 | 1,169,089 | 1,009,804 | 859,541 | 737,043 |
| 1993 | 0.0368 | 7,782,740 | 3,865,519 | 2,800,953 | 2,173,659 | 1,777,069 | 1,508,637 | 1,297,510 | 1,131,726 | 986,989 | 862,463 | 764,147 | 668,896 | 589,089 |
| 1994 | 0.0349 | 7,051,523 | 3,536,087 | 2,604,472 | 2,047,354 | 1,691,005 | 1,447,552 | 1,254,533 | 1,101,858 | 967,636 | 851,358 | 758,955 | 668,854 | 592,862 |
| 1995 | 0.0380 | 10,256,088 | 5,063,599 | 3,631,862 | 2,795,954 | 2,271,296 | 1,918,242 | 1,641,938 | 1,425,964 | 1,238,222 | 1,077,390 | 950,924 | 828,891 | 727,066 |
| 1996 | 0.0443 | 10,605,458 | 5,067,054 | 3,436,635 | 2,531,710 | 1,985,942 | 1,630,224 | 1,359,352 | 1,152,856 | 977,566 | 830,902 | 718,118 | 611,657 | 524,812 |
| Mean ${ }^{\text {a }}$ | 0.0336 | 12,156,546 | 6,137,240 | 4,572,484 | 3,626,994 | 3,017,272 | 2,597,984 | 2,263,686 | 1,997,900 | 1,763,099 | 1,558,701 | 1,395,528 | 1,235,699 | 1,100,272 |
| Mean ${ }^{\text {b }}$ | 0.0391 | 10,477,685 | 5,141,469 | 3,649,477 | 2,786,560 | 2,248,958 | 1,889,339 | 1,609,329 | 1,391,476 | 1,202,937 | 1,042,130 | 916,208 | 795,197 | 694,650 |

${ }^{2}$ Mean 1977-1996

Table 5
Biomass (t) of North American Atlantic salmon from river exit to sea age 1 year, by month.

| Smolt year (Yr) | Date |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Jun | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Mean |
|  | 1 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 1 |  |
| 0\% mortality at river exit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1977 | 231 | 315 | 558 | 939 | 1,436 | 1,874 | 2,087 | 2,045 | 1,860 | 1,630 | 1,433 | 1,260 | 1,155 | 1,135 | 1,167 | 1,364 |
| 1978 | 82 | 128 | 285 | 575 | 1,017 | 1,490 | 1,849 | 1,998 | 2,003 | 1,933 | 1,853 | 1,792 | 1,799 | 1,935 | 2,082 | 1,435 |
| 1979 | 230 | 333 | 649 | 1,183 | 1,926 | 2,642 | 3,083 | 3,152 | 2,990 | 2,732 | 2,493 | 2,284 | 2,178 | 2,225 | 2,334 | 2,144 |
| 1980 | 528 | 714 | 1,242 | 2,067 | 3,132 | 4,054 | 4,483 | 4,366 | 3,944 | 3,435 | 3,002 | 2,623 | 2,391 | 2,334 | 2,393 | 2,907 |
| 1981 | 401 | 546 | 963 | 1,620 | 2,476 | 3,226 | 3,591 | 3,517 | 3,196 | 2,799 | 2,459 | 2,161 | 1,980 | 1,943 | 1,998 | 2,344 |
| 1982 | 92 | 136 | 277 | 522 | 874 | 1,226 | 1,460 | 1,521 | 1,470 | 1,368 | 1,270 | 1,184 | 1,149 | 1,195 | 1,264 | 1,050 |
| 1983 | 432 | 564 | 923 | 1,465 | 2,137 | 2,681 | 2,882 | 2,735 | 2,408 | 2,044 | 1,747 | 1,488 | 1,324 | 1,262 | 1,278 | 1,820 |
| 1984 | 358 | 487 | 856 | 1,437 | 2,192 | 2,853 | 3,170 | 3,102 | 2,815 | 2,463 | 2,161 | 1,897 | 1,736 | 1,702 | 1,749 | 2,067 |
| 1985 | 283 | 398 | 741 | 1,302 | 2,058 | 2,757 | 3,148 | 3,155 | 2,934 | 2,629 | 2,357 | 2,118 | 1,983 | 1,989 | 2,066 | 2,121 |
| 1986 | 275 | 388 | 726 | 1,279 | 2,028 | 2,722 | 3,114 | 3,127 | 2,913 | 2,615 | 2,349 | 2,114 | 1,983 | 1,992 | 2,071 | 2,104 |
| 1987 | 244 | 344 | 647 | 1,143 | 1,817 | 2,444 | 2,801 | 2,818 | 2,630 | 2,365 | 2,127 | 1,918 | 1,801 | 1,813 | 1,886 | 1,897 |
| 1988 | 174 | 246 | 463 | 819 | 1,303 | 1,754 | 2,012 | 2,026 | 1,892 | 1,702 | 1,532 | 1,383 | 1,300 | 1,309 | 1,363 | 1,365 |
| 1989 | 202 | 280 | 512 | 884 | 1,380 | 1,829 | 2,067 | 2,054 | 1,893 | 1,682 | 1,496 | 1,333 | 1,238 | 1,231 | 1,274 | 1,375 |
| 1990 | 163 | 227 | 419 | 731 | 1,148 | 1,531 | 1,739 | 1,736 | 1,608 | 1,434 | 1,282 | 1,147 | 1,070 | 1,068 | 1,108 | 1,165 |
| 1991 | 308 | 407 | 683 | 1,106 | 1,638 | 2,082 | 2,264 | 2,172 | 1,932 | 1,658 | 1,430 | 1,231 | 1,106 | 1,065 | 1,084 | 1,444 |
| 1992 | 313 | 408 | 668 | 1,060 | 1,546 | 1,940 | 2,085 | 1,979 | 1,742 | 1,479 | 1,263 | 1,076 | 958 | 913 | 924 | 1,317 |
| 1993 | 162 | 220 | 385 | 644 | 980 | 1,272 | 1,412 | 1,379 | 1,249 | 1,091 | 956 | 837 | 765 | 749 | 769 | 918 |
| 1994 | 147 | 201 | 358 | 606 | 932 | 1,221 | 1,365 | 1,342 | 1,225 | 1,077 | 949 | 837 | 770 | 759 | 782 | 896 |
| 1995 | 213 | 288 | 499 | 828 | 1,252 | 1,618 | 1,786 | 1,737 | 1,567 | 1,363 | 1,190 | 1,038 | 945 | 921 | 944 | 1,156 |
| 1996 | 221 | 288 | 472 | 750 | 1,095 | 1,375 | 1,479 | 1,404 | 1,237 | 1,051 | 898 | 766 | 682 | 650 | 659 | 934 |
| Mean 1977-1996 | 253 | 349 | 628 | 1,074 | 1,664 | 2,191 | 2,463 | 2,434 | 2,231 | 1,972 | 1,746 | 1,547 | 1,430 | 1,415 | 1,460 | 1,626 |
| Mean 1990-1996 | 218 | 292 | 501 | 825 | 1,240 | 1,594 | 1,751 | 1,695 | 1,522 | 1,318 | 1,146 | 996 | 903 | 876 | 896 | 1,128 |
| 20\% mortality at river exit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1977 | 231 | 257 | 469 | 810 | 1,264 | 1,676 | 1,894 | 1,882 | 1,735 | 1,541 | 1,371 | 1,221 | 1,134 | 1,128 | 1,167 | 1,260 |
| 1978 | 82 | 104 | 240 | 496 | 895 | 1,333 | 1,678 | 1,838 | 1,868 | 1,827 | 1,772 | 1,736 | 1,765 | 1,923 | 2,082 | 1,344 |
| 1979 | 230 | 271 | 546 | 1,020 | 1,695 | 2,363 | 2,799 | 2,900 | 2,789 | 2,582 | 2,385 | 2,213 | 2,138 | 2,212 | 2,334 | 1,993 |
| 1980 | 528 | 582 | 1,045 | 1,783 | 2,757 | 3,626 | 4,069 | 4,017 | 3,679 | 3,246 | 2,872 | 2,542 | 2,346 | 2,319 | 2,393 | 2,683 |
| 1981 | 401 | 445 | 810 | 1,398 | 2,179 | 2,886 | 3,259 | 3,236 | 2,981 | 2,646 | 2,352 | 2,094 | 1,943 | 1,931 | 1,998 | 2,166 |
| 1982 | 92 | 111 | 233 | 450 | 769 | 1,096 | 1,326 | 1,400 | 1,371 | 1,293 | 1,214 | 1,148 | 1,128 | 1,187 | 1,264 | 979 |
| 1983 | 432 | 459 | 777 | 1,264 | 1,880 | 2,398 | 2,616 | 2,516 | 2,246 | 1,932 | 1,671 | 1,442 | 1,300 | 1,254 | 1,278 | 1,673 |
| 1984 | 358 | 397 | 720 | 1,240 | 1,929 | 2,551 | 2,878 | 2,854 | 2,625 | 2,328 | 2,067 | 1,838 | 1,704 | 1,692 | 1,749 | 1,909 |
| 1985 | 283 | 324 | 624 | 1,123 | 1,811 | 2,466 | 2,857 | 2,903 | 2,736 | 2,485 | 2,255 | 2,053 | 1,946 | 1,976 | 2,066 | 1,966 |
| 1986 | 275 | 316 | 611 | 1,103 | 1,784 | 2,435 | 2,827 | 2,877 | 2,717 | 2,472 | 2,247 | 2,049 | 1,946 | 1,979 | 2,071 | 1,951 |
| 1987 | 244 | 281 | 544 | 986 | 1,599 | 2,186 | 2,543 | 2,593 | 2,453 | 2,235 | 2,034 | 1,858 | 1,768 | 1,801 | 1,886 | 1,760 |
| 1988 | 174 | 200 | 389 | 706 | 1,146 | 1,569 | 1,827 | 1,864 | 1,765 | 1,609 | 1,466 | 1,340 | 1,276 | 1,301 | 1,363 | 1,266 |
| 1989 | 202 | 229 | 431 | 763 | 1,214 | 1,636 | 1,877 | 1,890 | 1,766 | 1,589 | 1,431 | 1,292 | 1,215 | 1,223 | 1,274 | 1,273 |
| 1990 | 163 | 185 | 353 | 630 | 1,010 | 1,369 | 1,579 | 1,597 | 1,499 | 1,356 | 1,226 | 1,111 | 1,050 | 1,062 | 1,108 | 1,079 |
| 1991 | 308 | 332 | 575 | 954 | 1,442 | 1,862 | 2,055 | 1,998 | 1,802 | 1,567 | 1,368 | 1,193 | 1,086 | 1,058 | 1,084 | 1,330 |
| 1992 | 313 | 333 | 562 | 914 | 1,361 | 1,735 | 1,893 | 1,821 | 1,625 | 1,398 | 1,208 | 1,043 | 940 | 907 | 924 | 1,211 |
| 1993 | 162 | 179 | 324 | 555 | 862 | 1,138 | 1,281 | 1,268 | 1,165 | 1,031 | 914 | 812 | 751 | 745 | 769 | 848 |
| 1994 | 147 | 164 | 301 | 523 | 820 | 1,092 | 1,239 | 1,235 | 1,142 | 1,018 | 908 | 812 | 756 | 754 | 782 | 828 |
| 1995 | 213 | 234 | 420 | 715 | 1,102 | 1,447 | 1,621 | 1,598 | 1,462 | 1,288 | 1,138 | 1,006 | 927 | 915 | 944 | 1,067 |
| 1996 | 221 | 235 | 397 | 647 | 964 | 1,230 | 1,342 | 1,292 | 1,154 | 993 | 859 | 742 | 669 | 646 | 659 | 859 |
| Mean 1977-1996 | 253 | 284 | 529 | 927 | 1,464 | 1,960 | 2,236 | 2,239 | 2,081 | 1,863 | 1,670 | 1,499 | 1,403 | 1,406 | 1,460 | 1,505 |
| Mean 1990-1996 | 218 | 238 | 422 | 712 | 1,091 | 1,425 | 1,589 | 1,560 | 1,420 | 1,246 | 1,096 | 965 | 886 | 871 | 896 | 1,061 |
| 40\% mortality at river exit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1977 | 231 | 198 | 375 | 670 | 1,072 | 1,451 | 1,672 | 1,690 | 1,585 | 1,432 | 1,294 | 1,172 | 1,107 | 1,119 | 1,167 | 1,141 |
| 1978 | 82 | 80 | 192 | 410 | 759 | 1,154 | 1,481 | 1,651 | 1,708 | 1,699 | 1,674 | 1,667 | 1,723 | 1,908 | 2,082 | 1,239 |
| 1979 | 230 | 208 | 437 | 844 | 1,437 | 2,046 | 2,470 | 2,605 | 2,549 | 2,401 | 2,252 | 2,126 | 2,087 | 2,194 | 2,334 | 1,820 |
| 1980 | 528 | 447 | 837 | 1,474 | 2,338 | 3,140 | 3,592 | 3,608 | 3,362 | 3,019 | 2,712 | 2,441 | 2,290 | 2,301 | 2,393 | 2,428 |
| 1981 | 401 | 342 | 649 | 1,155 | 1,848 | 2,499 | 2,877 | 2,907 | 2,724 | 2,460 | 2,221 | 2,011 | 1,897 | 1,916 | 1,998 | 1,962 |
| 1982 | 92 | 85 | 186 | 372 | 652 | 950 | 1,170 | 1,257 | 1,253 | 1,203 | 1,147 | 1,102 | 1,101 | 1,178 | 1,264 | 897 |
| 1983 | 432 | 353 | 622 | 1,044 | 1,595 | 2,076 | 2,309 | 2,260 | 2,053 | 1,796 | 1,577 | 1,385 | 1,268 | 1,244 | 1,278 | 1,506 |
| 1984 | 358 | 305 | 577 | 1,025 | 1,636 | 2,209 | 2,540 | 2,563 | 2,400 | 2,164 | 1,952 | 1,765 | 1,663 | 1,678 | 1,749 | 1,729 |
| 1985 | 283 | 249 | 499 | 928 | 1,536 | 2,135 | 2,522 | 2,607 | 2,501 | 2,310 | 2,129 | 1,971 | 1,899 | 1,960 | 2,066 | 1,788 |
| 1986 | 275 | 243 | 489 | 912 | 1,513 | 2,108 | 2,495 | 2,584 | 2,483 | 2,298 | 2,121 | 1,968 | 1,899 | 1,964 | 2,071 | 1,775 |
| 1987 | 244 | 216 | 436 | 815 | 1,356 | 1,893 | 2,245 | 2,329 | 2,242 | 2,078 | 1,921 | 1,785 | 1,725 | 1,787 | 1,886 | 1,602 |
| 1988 | 174 | 154 | 312 | 584 | 972 | 1,359 | 1,612 | 1,674 | 1,613 | 1,496 | 1,384 | 1,287 | 1,245 | 1,290 | 1,363 | 1,152 |
| 1989 | 202 | 176 | 345 | 630 | 1,030 | 1,416 | 1,657 | 1,698 | 1,614 | 1,478 | 1,351 | 1,240 | 1,186 | 1,214 | 1,274 | 1,156 |
| 1990 | 163 | 142 | 282 | 521 | 857 | 1,185 | 1,394 | 1,435 | 1,370 | 1,261 | 1,157 | 1,067 | 1,024 | 1,053 | 1,108 | 981 |
| 1991 | 308 | 255 | 460 | 788 | 1,223 | 1,612 | 1,814 | 1,795 | 1,647 | 1,457 | 1,291 | 1,145 | 1,059 | 1,050 | 1,084 | 1,200 |
| 1992 | 313 | 255 | 450 | 756 | 1,154 | 1,502 | 1,671 | 1,635 | 1,485 | 1,299 | 1,141 | 1,002 | 917 | 900 | 924 | 1,090 |
| 1993 | 162 | 138 | 259 | 459 | 731 | 986 | 1,131 | 1,139 | 1,065 | 959 | 863 | 779 | 733 | 739 | 769 | 768 |
| 1994 | 147 | 126 | 241 | 433 | 696 | 946 | 1,094 | 1,109 | 1,044 | 946 | 857 | 779 | 738 | 748 | 782 | 751 |
| 1995 | 213 | 180 | 336 | 591 | 935 | 1,253 | 1,431 | 1,436 | 1,336 | 1,198 | 1,074 | 966 | 905 | 908 | 944 | 965 |

Table 6
Sizes of prey captured by seals in eastern Canada.

| Predator | Prey | $\begin{aligned} & \text { Prey length (cm) } \\ & \text { in predator samples } \end{aligned}$ |  |  | Prey length (cm) from trawl surveys |  |  | Location | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Minimum | Maximum | N | Minimum | Maximum | N |  |  |
| Grey seal | Fish | 10-20 | 50-60 |  |  |  |  | NW Gulf | Murie and Lavigne 1992 |
|  | Cod | 10-15 | 79.7 |  |  |  |  | Anticosti I | Benoit and Bowen 1990a |
|  | Plaice | <10 | >35 |  |  |  |  | Anticosti I | Benoit and Bowen 1990a |
|  | Lumpfish | <16 | >28 |  |  |  |  | Anticosti I | Benoit and Bowen 1990a |
|  | Mackerel | <27 | >45 |  |  |  |  | Anticosti I | Benoit and Bowen 1990a |
|  | Herring | <22 | >36 |  |  |  |  | Anticosti I | Benoit and Bowen 1990a |
|  | Capelin | 10-11 | >17 |  |  |  |  | Anticosti I | Benoit and Bowen 1990a |
|  | Cod | 10-15 | 55-60 | 115 |  |  |  | Grand Manan, eastern NS, Sable I | Bowen et al. 1993 |
|  | Pollock | 5-10 | 35-40 | 55 |  |  |  | Grand Manan, eastern NS, Sable I | Bowen et al. 1993 |
|  | Silver hake | 10-15 | 45-50 | 43 |  |  |  | Grand Manan, eastern NS, Sable I | Bowen et al. 1993 |
|  | Herring | 5-10 | 40-45 | 160 |  |  |  | Grand Manan, eastern NS, Sable I | Bowen et al. 1993 |
|  | Sand lance | 5-10 | 25-30 | 139 |  |  |  | Grand Manan, eastern NS, Sable I | Bowen et al. 1993 |
|  | Squid | 10-15 | 25-30 | 78 |  |  |  | Grand Manan, eastern NS, Sable I | Bowen et al. 1993 |
|  | Cod | 0-5 | 45-50 | 81 | 5-10 | 45-50 |  | Sable I | Bowen and Harrison 1994 |
|  | Redfish | 10-15 | 25-30 | 71 | 5-10 | 30-35 |  | Sable I | Bowen and Harrison 1994 |
|  | Silver hake | 15-20 | 35-40 | 30 | 20-25 | 35-40 |  | Sable I | Bowen and Harrison 1994 |
|  | Plaice | 15-20 | 40-45 | 23 | 5-10 | 40-45 |  | Sable I | Bowen and Harrison 1994 |
|  | Yellowtail | 10-15 | 40-45 | 27 | 15-20 | 40-45 |  | Sable I | Bowen and Harrison 1994 |
|  | Sand lance | 3-7 | 28-32 | 876 |  |  |  | Sable I | Bowen and Harrison 1994 |
| Harbour seal | Cod | 5-10 | 50-55 |  |  |  |  | Bay of Fundy | Bowen and Harrison 1996 |
|  | Pollock | 5-10 | 30-35 |  |  |  |  | Bay of Fundy | Bowen and Harrison 1996 |
|  | Herring | 10-15 | 35-40 |  |  |  |  | Bay of Fundy | Bowen and Harrison 1996 |
|  | Squid | 5-10 | 20-25 |  |  |  |  | Bay of Fundy | Bowen and Harrison 1996 |
|  | Cod | 10-15 | 35-40 |  |  |  |  | E Cape Breton, Eastern Shore NS | Bowen and Harrison 1996 |
|  | Pollock | 10-15 | 35-40 |  |  |  |  | E Cape Breton, Eastern Shore NS | Bowen and Harrison 1996 |
|  | Herring | 15-20 | 35-40 |  |  |  |  | E Cape Breton, Eastern Shore NS | Bowen and Harrison 1996 |
|  | Squid | 15-20 | 25-30 |  |  |  |  | E Cape Breton, Eastern Shore NS | Bowen and Harrison 1996 |
| Harp seal | Cod | 24-26 | 54-56 | 90 | 30-32 | 75-77 | 17,088 | Newfoundland | Lawson and Stenson 1997 |
|  | Cod |  | 50.5 | 212 |  |  |  | Newfoundland | Lawson and Stenson 1997 |
|  | Cod | 10 | 57.1 | 390 |  |  |  | Newfoundland | Lawson et al. 1995 |
|  | Herring | 6 | 37 | 340 |  |  |  | Newfoundland | Lawson et al. 1995 |
|  | Capelin | 3 | 18 | 2,220 |  |  |  | Newfoundland | Lawson et al. 1995 |
|  | Arctic cod | 2 | 30 | 3,369 |  |  |  | Newfoundland | Lawson et al. 1995 |
|  | Capelin | 8.8 | 15.7 | 270 |  |  |  | St. Lawrence estuary | Beck et al. 1993 |
| Hooded seal | Redfish | 24 | 48.1 | 29 |  |  |  | Newfoundland | Ross 1992 |
|  | Greenland halibut | 18.6 | 45.1 | 57 |  |  |  | Newfoundland | Ross 1992 |
|  | Herring | 21.8 | 35.6 | 22 |  |  |  | Newfoundland | Ross 1992 |
|  | Capelin | 14.8 | 16.9 | 5 |  |  |  | Newfoundland | Ross 1992 |
|  | Arctic cod | 13.4 | 24.9 | 23 |  |  |  | Newfoundland | Ross 1992 |

Table 7
Sizes of prey captured by seabirds which potentially prey on salmon in eastern Canada.

| Predator | Prey | $\begin{gathered} \text { Prey size in } \\ \text { predator samples } \end{gathered}$ |  |  | Prey length (cm) available |  |  | Location | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Minimum | Maximum | N | Minimum | Maximum | N |  |  |
| Northern Fulmar | Redfish | 2.7 | 11.9 | 90 |  |  |  | Barents Sea | Erikstad 1990 |
|  | Cod | 1.9 | 13.6 | 31 |  |  |  | Barents Sea | Erikstad 1990 |
|  | Polar cod | 4.0 | 13.2 | 32 |  |  |  | Barents Sea | Erikstad 1990 |
|  | Polar cod | 9.3 | 11.0 | 7 |  |  |  | Svalbard | Gjertz et al. 1985 |
|  | Sand lance | 0 | 17 | 795 | 5 | 17 | 231 | Shetland | Fowler and Dye 1987 |
|  | Discarded haddock | 15 | 30 | 40 | 19 | 36 | 2,859 | Shetland | Hudson and Furness 1988 |
|  | Discarded whiting | 14 | 29 | 36 | 18 | 36 | 2,589 | Shetland | Hudson and Furness 1988 |
| Greater shearwater | Illex squid |  | 20 |  |  |  |  | Bay of Fundy | Brown et al. 1981 |
|  | Mackerel |  | 20 |  |  |  |  | Bay of Fundy | Brown et al. 1981 |
| Black-legged kittiwake | Fish | 6 | 16 |  |  |  |  | Alaska | Baird 1994 |
|  | Cod | 3.6 | 13.4 | 53 | 7 | 14 | 333 | Barents Sea | Erikstad 1990 |
|  | Redfish | 4.8 | 6.2 | 37 | 5 | 14 | 1,125 | Barents Sea | Erikstad 1990 |
|  | Arctic cod | 6.7 | 13.7 | 44 | 5 | 14 | 141 | Barents Sea | Erikstad 1990 |
|  | Fish | 6-8 | 14-16 | 9 |  |  |  | Norway | Furness and Barrett 1985 |
| Herring gull | Capelin | 28 g | 49 g | 41 |  |  |  | Witless Bay, Newfoundland | Pierotti 1983 |
|  | Squid | 68 g | 121 g | 24 |  |  |  | Witless Bay, Newfoundland | Pierotti 1983 |
|  | Smelt | 7 | 17.4 | 86 |  |  |  | Southern Ontario | Ewins et al. 1994 |
|  | Alewife | 7.5 g | 19.9 | 5 |  |  |  | Southern Ontario | Ewins et al. 1994 |
|  | Red drum | 16 | 23 | 615 |  |  |  | Southern Ontario | Ewins et al. 1994 |
|  | Fish | 10-12 | 14-16 | 5 |  |  |  | Norway | Furness and Barrett 1985 |
|  | Discarded haddock | 22 | 31 | 38 | 19 | 36 | 2,859 | Shetland | Hudson and Furness 1988 |
|  | Discarded whiting | 15 | 30 | 44 | 18 | 36 | 2,589 | Shetland | Hudson and Furness 1988 |
| Great black-backed gull | Discarded haddock | 19 | 38 | 1126 | 19 | 36 | 2,859 | Shetland | Hudson and Furness 1988 |
|  | Discarded whiting | 20 | 39 | 1025 | 18 | 36 | 2,589 | Shetland | Hudson and Furness 1988 |
| Glaucous gull | Cod | 4.4 | 5.3 | 3 | 7 | 14 | 333 | Barents Sea | Erikstad 1990 |
|  | Redfish | 5.4 | 5.7 | 4 | 5 | 14 | 1,125 | Barents Sea | Erikstad 1990 |
|  | Arctic cod | 7.6 | 13.5 | 13 | 5 | 14 | 141 | Barents Sea | Erikstad 1990 |
| Common murre | Capelin ${ }^{\text {b }}$ | 8.3 | 18.3 | 47 |  |  |  | Gannet Islands, Labrador | Bradstreet 1983 |
|  | Sand lance ${ }^{\text {b }}$ | 6.2 | 13.2 | 36 |  |  |  | Gannet Islands, Labrador | Bradstreet 1983 |
|  | Capelin | 8-10 | 16-18 | 2,261 |  |  |  | Gannet Islands, Labrador | Birkhead and Nettleship 1987 |
|  | Daubed shanny | 10-12 | 16-18 | 394 |  |  |  | Gannet Islands, Labrador | Birkhead and Nettleship 1987 |
|  | Arctic cod | 6-8 | 14-16 | 179 |  |  |  | Gannet Islands, Labrador | Birkhead and Nettleship 1987 |
|  | Fish | 11 | 17 | 1,580 |  |  |  | Norway | Furness and Barrett 1985 |
|  | Capelin | 13.0 | 16.9 | 68 | 13.7 cm | 18.5 cm |  | Norway | Erikstad and Vader 1989 |
|  | Smelt |  | 22 |  |  |  |  | Netherlands (lab study) | Swennen and Duiven 1977 |
|  | Fish |  | 20 |  |  |  |  | Theoretical calculations | Bradstreet and Brown 1985 |
|  | Fish |  | 113 g |  |  |  |  | Laboratory observations | Golovkin 1963, quoted by Bradstreet and |
| Thick-billed murre | Capelin | 8-10 | 16-18 | 168 |  |  |  | Gannet Islands, Labrador | Birkhead and Nettleship 1987 |
|  | Arctic cod | 8-10 | 14-16 | 8 |  |  |  | Gannet Islands, Labrador | Birkhead and Nettleship 1987 |
|  | Daubed shanny | 8-10 | 18-20 | 313 |  |  |  | Gannet Islands, Labrador | Birkhead and Nettleship 1987 |
|  | Arctic cod | 4-6 | 18-20 | 176 |  |  |  | Hudson Strait, Hudson Bay | Gaston and Noble 1985 |
|  | Food | 0.7 g | 41.5 g | 212 |  |  |  | Hudson Strait, Hudson Bay | Gaston 1985 |
|  | Food | 2.8 | 19.3 | 140 |  |  |  | Prince Leopold I, Lancaster Sound | Gaston and Nettleship 1981 |
|  | Cod | 3.2 | 12.1 | 42 |  |  |  | Barents Sea | Erikstad 1990 |
|  | Arctic cod | 11.1 | 14.3 | 8 |  |  |  | Barents Sea | Erikstad 1990 |
|  | Fish | 11 | 11 | 50 |  |  |  | Norway | Furness and Barrett 1985 |
|  | Capelin | 12.5 | 18.5 | 43 | 12.9 cm | 18.5 cm | 136 | Norway | Erikstad and Vader 1989 |

[^1]Table 8
Vulnerability windows of Atlantic salmon to seal and seabird predation

| Predator | Prey | Susceptible prey sizes |  | Geographic overlap |  | Vulnerability window |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Lengths (cm) | Dates | Area | Dates |  |
| Grey seal | Post-smolt | All | All | Gulf, Scotian Shelf | 1 Jun-31 Oct | 1 Jun-31 Oct |
|  | 1SW | All | All | Gulf, Scotian Shelf | 15 May-31 Oct | 15 May-31 Oct |
| Harbour seal | Post-smolt | All | All | Lab, Nfld, Gulf, Scotian Shelf | 1 Jun-31 Dec | 1 Jun-31 Dec |
|  | 1SW | All | All | Lab, Nfld, Gulf, Scotian Shelf | 1 Jan-31 Dec | 1 Jan-31 Dec |
| Harp seal | Post-smolt | All | All | Lab, Nfld, Gulf | 1 Jun-31 Dec | 1 Jun-31 Dec |
|  | 1SW | All | All | Lab, Nfld, Gulf | 1 Jan-31 Dec | 1 Jan-31 Dec |
| Hooded seal | Post-smolt | All | All | Lab, Nfld, Gulf | 1-31 Dec | 1-31 Dec |
|  | 1SW | All | All | Lab, Nfld, Gulf | 1 Jan-31 May, 1-31 Dec | 1 Jan-31 May, 1-31 Dec |
| Northern fulmar | Post-smolt | $\leq 17$ | 1 Jun-4 Jul | Lab Sea, N\&S Lab Banks, Nfld Banks ${ }^{\text {a }}$ | 1 Jan-31 Dec | 1 Jun-4 Jul |
| Shearwaters | Post-smolt | $\leq 20$ | 1 Jun-22 Jul | Lab Sea, N\&S Lab Banks, Nfld Banks, Scotian Shelf | May-Nov | 1 Jun-22 Jul |
| Black-legged kittiwake | Post-smolt | $\leq 15$ | 1-17 Jun | Lab Sea, N\&S Lab Banks, Nfld Banks, Gulf | 1 Jan-31 Dec | 1-17 Jun |
| Gulls | Post-smolt | $\leq 31$ | 1 Jun-7 Sep | Lab Sea, N\&S Lab Banks, Nfld Banks, Gulf, Scotian Shelf | 1 Jan-31 Dec | 1 Jun-7 Sep |
| Common murre | Post-smolt | $\leq 17$ | 1 Jun-4 Jul | Lab Sea, N\&S Lab Banks, Nfld Banks, Gulf | 1 Jan-31 Dec | 1 Jun-4 Jul |

${ }^{2}$ For bird predators, areas defined by Diamond et al. 1993 as follows: Labrador Sea - from the edge of the continental shelf to $45^{\circ} \mathrm{W}$ and $60^{\circ} \mathrm{N}$;
Northern Labrador Banks - the continental shelf from $60^{\circ} \mathrm{N}$ to $53^{\circ} \mathrm{N}$; Southern Labrador Banks - the continental shelf
from $53^{\circ} \mathrm{N}$ to $50^{\circ} \mathrm{N}$; Newfoundland Banks - the continental shelf east, southeast, and south of Newfoundland.

Table 9
Records of salmon predation derived from stomach samples of seals and seabirds (other than northern gannets) in eastern Canada. Lengths are estimated from otolith size.

| Predator | Location | Date | Number <br> of stomachs containing salmon | $\begin{aligned} & \text { Type } \\ & \text { of } \\ & \text { remains } \end{aligned}$ | Number <br> of <br> salmon per stomach | Salmon length (cm) |  |  | Comments | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  | Mean | Range | N |  |  |
| Grey seal | Miramichi estuary | Summer, 1950-1954 | 3 | Fish | 1 | Adults |  |  | Uncertain if salmon were wild-caught or stolen from nets | Fisher and Mackenzie 1955 |
| Grey seal | Miramichi estuary | ~1968-1970 | 1 | Fish | 1 | NA |  |  | Uncertain if salmon were wild-caught or stolen from nets | Mansfield and Beck 1977 |
| Grey seal | Magdalen Islands | ~1968-1970 | 1 | Fish | 1 | NA |  |  |  | Mansfield and Beck 1977 |
| Grey seal | Anticosti I. | 4 Jul-20 Aug 1986 | 1 | Otolith | 6 | 43.0 | 35.7-52. 1 | 5 | Calculated size is smaller than expected for this location and time | Benoit and Bowen 1990a |
| Harbour seal | Murre Ledge, near Grand Manan I., Bay of Fundy | 3 Jul 1990 | 1 | Tag | 1 |  |  |  | Tag had been applied to a hatchery smolt that was released in the Stewiacke R, NS, in May 1990 | B. Beck, DFO Science (retired), pers. comm. |
| Harp seal | Les Escoumins, St. Lawrence estuary | 14-16 Apr 1989 | 1 | Otolith, flesh | 1 | $29.1{ }^{\text {a }}$ | - | 1 | Calculated size is unexpected for this location and time. | Beck et al. 1993 |
| Harp seal | Brighton, Notre Dame Bay, Nfld | 3 May 1993 | 1 | Otolith | 1 | 34 |  | 1 | Calculated size is unexpected for this location and time. Seal was a male aged 23. | O'Connell et al. 1998, G. Stenson pers. comm. |
| Common murre | Witless Bay, eastern Newfoundland | 13 Jul 1984 | 1 | Tag | 1 |  |  |  | Tag had been applied to a smolt on the St. Croix River, May 1984 | D. Methven and J. Piatt in Montevecchi et al. 1988. |

${ }^{2}$ Salmon remains weighing 445 g were found in 1 stomach of a sample of 9 stomachs, whose pooled contents weighed $23,348 \mathrm{~g}$. Hence salmon remains accounted for $445 /(23348 / 9)=0.17$ of the contents of one stomach.

Table 10
Sight records of seal-salmonid interactions in Newfoundland and Labrador.

| Predator | Location | Date | Number of seals observed | Observation | Possibility that salmon was stolen from a net ${ }^{\text {a }}$ | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Grey seal | St. Marys Bay, Newfoundland | Jun 1980 | 1 | Seal observed with adult salmon in its mouth | Yes | DFO technical staff |
| Harp seal | Twillingate, Newfoundland | Winter 1996 | 1 | Seal observed on offshore ice with salmon kelt | No | DFO Fisheries Officer |
| Grey seal | White Bear River estuary, Labrador | Jul 1998 | 1 | Seal observed with adult salmon in its mouth | No | DFO Fisheries guardian |
| Harbour seal | Waterford River, Newfoundland | Feb 1999 | 1 | Seal observed with a salmon or trout parr in its mouth | No | Reddin |
| Grey seal | Paradise River estuary, Labrador | Jun-Jul 1999 | 1 | Seal observed with adult salmon in its mouth | Yes | DFO technical staff |
| Grey seal | Southwest Tributary, <br> Paradise River, <br> Labrador | Jul 1999 | 1 | Seal chasing adult salmon into trap | No | DFO technical staff at counting fence |

${ }^{2}$ Marked Yes if commercial fisheries may have been operating in the vicinity; otherwise marked No.

Table 11
Sample sizes of seal diet studies in eastern Canada.

| Predator | Sample size |  | Number of samples containing salmon | Date | Region | Location | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Total samples | Samples containing food |  |  |  |  |  |
| Grey seal | 82 | 41 | 0 | Jul-Dec 1983 | Northern Gulf | St. Lawrence estuary, western Anticosti I | Murie and Lavigne 1992 |
|  | 744 | 295 | 1 | 14 Jun-20 Aug 1982-1987 | Northern Gulf | Anticosti I | Benoit and Bowen 1990a |
|  | 782 | 316 | 1 | 1983-1987 | Northern Gulf | Anticosti, other unnamed locations | Benoit and Bowen 1990b (includes new and all previously published data) |
|  |  | 114 | NA | May-Aug 1988 | Northern Gulf | Anticosti I | Proust and Hammill unpubl., cited by Hammill and Mohn 1994 |
|  |  | 100 | NA | Aug-Sep 1992 | Northern Gulf | Anticosti I | Proust and Hammill unpubl., cited by Hammill and Mohn 1994 |
|  | 67 | NA | 1 | Mostly 1968-1970 | Southern Gulf | Magdalen Islands | Mansfield and Beck 1977 |
|  | >22 | NA | 3 | May-Nov, 1950-1954 (stomachs containing salmon were collected in summer) | Southern Gulf | Miramichi estuary | Fisher and Mackenzie 1955 |
|  | <36 | NA | 2 | Mostly 1968-1970 | Southern Gulf | Miramichi estuary | Mansfield and Beck 1977 |
|  | 58 | NA | 4 | 1950-1970 | Southern Gulf | Miramichi estuary | Mansfield and Beck 1977, including data from Fisher and Mackenzie 1955 |
|  | 18 | NA | 0 | Mostly 1968-1970 | Southern Gulf | Amet I | Mansfield and Beck 1977 |
|  | 143 | NA | 5 | 1950-1970 | Southern Gulf |  | Mansfield and Beck 1977, including data from Fisher and Mackenzie 1955 |
|  | 194 | 89 | $5^{\text {a }}$ | 1950-1987 | Southern Gulf | Locations indicated by Mansfield and Beck 1977 (including data from Fisher and Mackenzie 1955), unnamed coastal locations | Benoit and Bowen 1990b (includes new and all previously published data) |
|  | 35 | 7 | 0 | Jan 1990-1991 | Southern Gulf | St. Georges Bay | Baker et al. 1995 |
|  | <22 | NA | 0 | May-Nov, 1950-1954 | Scotian Shelf | East coast of NS | Fisher and Mackenzie 1955 |
|  | 137-154 | NA | 0 | Mostly 1968-1970 | Scotian Shelf | Fouchu and Gabarouse Bay | Mansfield and Beck 1977 |
|  | 62 | NA | 0 | Mostly 1968-1970 | Scotian Shelf | Camp I | Mansfield and Beck 1977 |
|  | 606 | 213 | 0 | 1950-1987 | Scotian Shelf | Coastal NS | Benoit and Bowen 1990b (includes new and all previously published data) |

Table 11 (continued)

| Predator | Sample size |  | Number of samples containing salmon | Date | Region | Location | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\begin{aligned} & \hline \text { Total } \\ & \text { samples } \end{aligned}$ | Samples containing food |  |  |  |  |  |
| Grey seal |  | 94 | 0 | Sep 1988-Nov 1990 | Scotian Shelf | Eastern shore NS | Bowen et al. 1993 |
|  |  | 198 | 0 | 1988-1993 | Scotian Shelf | Eastern shore NS | Mohn and Bowen 1996 (includes data from Bowen et al. 1993) |
|  | 247 | 47 | 0 | 1983-1984 | Scotian Shelf | Sable I | Benoit and Bowen 1990b |
|  |  | 37 | 0 | Feb-Dec 1990 | Scotian Shelf | Sable I | Bowen et al. 1993 |
|  | 393 | 365 | 0 | Jul 1991- Jan 1993 | Scotian Shelf | Sable I | Bowen and Harrison 1994 |
|  | 44 | 17 | 3 | May-Nov, 1950-1954 | Southern Gulf, Scotian Shelf |  | Fisher and Mackenzie 1955 |
|  | 446 | 207 | 5 | 1950-1970 | Southern Gulf, |  | Mansfield and Beck 1977, |
|  |  |  |  |  | Scotian Shelf |  | including data from Fisher and Mackenzie 1955 |
|  |  | 12 | 0 | Sep 1988-Jun 1990 | Fundy | Grand Manan | Bowen et al. 1993 |
|  | 528 | 143 | 0 | Sep 1988-Nov 1990 | Fundy, Scotian Shelf |  | Bowen et al. 1993 |
| Total |  | 1315 |  |  |  |  |  |
| Total with full ID |  | 1094 |  |  |  |  |  |
| Harbour seal | 11 | 11 | 0 | Jan-Feb 1998 | S Gulf | PEI | Cairns et al. unpubl. |
|  | 201 | 120 | 0 | Jun-Oct, 1950-1953 | S Gulf, Scotian | Pownal Bay, PEI; east coast | Fisher and Mackenzie 1955 |
|  |  |  |  |  | Shelf, Fundy | NS; south NB |  |
|  | 602 | 279 | 0 |  | Eastern Canada |  | Boulva and McLaren 1979 |
|  | 321 | 164 | $0^{\text {b }}$ | Jan-Oct, 1988-1992 | Fundy | Grand Manan | Bowen and Harrison 1996 |
|  | 148 | 85 | 0 | Feb-Nov, 1988-1992 | Scotian Shelf | E Cape Breton, Eastern Shore NS | Bowen and Harrison 1996 |
| Total | 1283 | 659 |  |  |  |  |  |
| Harp seal |  | 16 | NA | Apr-Sep 1990-1992 | Labrador | Inshore | Lawson et al. 1995 |
|  |  | 239 | NA | Oct-Mar 1990-1992 | Labrador | Inshore | Lawson et al. 1995 |
|  |  | 352 | 0 | 1982-1993 | Labrador | Inshore | Lawson and Stenson 1995 (includes data from Lawson et al. 1995) |
|  |  | 58 | 0 | Jan-Feb 1991-1995 | Newfoundland and Labrador | >30 km from shore, shot | Lawson and Stenson 1997 |
|  |  | 120 | 0 | Jan-Feb 1986-1995 | Newfoundland and Labrador | $>30 \mathrm{~km}$ from shore, from trawlers | Lawson and Stenson 1997 |
|  |  | 51 | 0 | Mar 1980-1995 | Newfoundland and Labrador | >30 km from shore, shot | Lawson and Stenson 1997 |
|  |  | 69 | 0 | Apr-May 1980-1995 | Newfoundland and Labrador | >30 km from shore, shot | Lawson and Stenson 1997 |
|  |  | 90 | 0 | May-Jul 1986-1995 | Newfoundland and Labrador | $>30 \mathrm{~km}$ from shore, gillnetted | Lawson and Stenson 1997 |
|  |  | 99 | NA | Apr-Sep 1990-1993 | Newfoundland | South coast, inshore | Lawson et al. 1995 |
|  |  | 243 | NA | Apr-Sep 1990-1993 | Newfoundland | Northeast coast, inshore | Lawson et al. 1995 |


| Predator | Sample size |  | Number of samples containing salmon | Date | Region | Location | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Total samples | Samples containing food |  |  |  |  |  |
| Harp seal |  | 308 | NA | Oct-Mar 1990-1993 | Newfoundland | Northeast coast, inshore | Lawson et al. 1995 |
|  |  | 1355 | 0 | 1982-1993 | Newfoundland | Northeast coast, inshore | Lawson and Stenson 1995 (includes data from Lawson et al. 1995) |
|  |  | 16 | NA | Oct-Mar 1990-1993 | Newfoundland | South coast, inshore | Lawson et al. 1995 |
|  |  | 181 | 0 | 1982-1993 | Newfoundland | South coast, inshore | Lawson and Stenson 1995 (includes data from Lawson et al. 1995) |
|  | 25 | 25 | 0 | 3 Jan-13 Feb 1983 | Northern Gulf | Les Escoumins | Murie and Lavigne 1991 |
|  | 41 | 41 | 0 | 20 Dec 1988-27 Feb 1989 | Northern Gulf | Les Escoumins | Beck et al 1993 |
|  | 10 | 9 | 1 | 14-16 Apr 1989 | Northern Gulf | Les Escoumins | Beck et al 1993 |
|  | 16 | 14 | 0 | 3-21 Dec 1989 | Northern Gulf | Harrington Harbour | Beck et al 1993 |
|  | 260 | 2 | 0 | 1-12 Jan, 1950-1952 | Northern Gulf | La Tabatière | Fisher and Mackenzie 1955 |
|  | 105 | 14 | 0 | 15-30 Jun 1953 | Northern Gulf | Blanc Sablon | Fisher and Mackenzie 1955 |
|  |  | 109 | 0 | Apr-Sep 1990-1993 | Northern Gulf | Newfoundland west coast, inshore | Lawson et al. 1995 |
|  |  | 96 | 0 | Oct-Mar 1990-1993 | Northern Gulf | Newfoundland west coast, inshore | Lawson et al. 1995 |
|  |  | 64 | NA | 1982-1993 | Northern Gulf | Newfoundland west coast | Lawson and Stenson 1995 |
|  |  | 241 | NA | Nov-Jun 1985-1993 | Northern Gulf | Newfoundland west coast | Stenson et al. 1997 (includes data from Lawson and Stenson 1995) |
|  |  | 126 | NA | Nov-Jun 1985-1993 | Northern Gulf | Newfoundland southwest coast | Stenson et al. 1997 (includes data from Lawson and Stenson 1995) |
|  | 199 | 45 | 0 | Mar 1976-1984 | Southern Gulf | Unspecified | Stewart and Murie 1986 |
|  | 81 | 81 | 0 | 21 Apr-16 May 1952 | Southern Gulf | Magdalen Islands | Fisher and Mackenzie 1955 |
|  | 164 | 62 | 0 | 3-20 Mar 1989 | Southern Gulf | Magdalen Islands | Beck et al. 1993 |
|  | 64 | 3 | 0 | 17 Feb-5 Apr 1949-1952 | Southern Gulf | SE of Magdalens, Port Hood NS, E of PEI, off Cape North, near St. Paul I. | Fisher and Mackenzie 1955 |
|  | 100 | 1 | 0 | 4 Apr 1952 | Scotian Shelf | East of Scatari Island | Fisher and Mackenzie 1955 |
| Total ${ }^{\text {c }}$ |  | 3145 |  |  |  |  |  |
| Total with full ID |  | 2083 |  |  |  |  |  |
| Hooded seal | 201 | 89 | 0 | Oct-Jun 1982-1990 | Newfoundland | Mostly northeast coast | Stenson et al. 1991 |
|  | 67 | 55 | 0 | Jan-May 1991 | Newfoundland | Mostly inshore on northeast coast | Ross 1992 |
|  | 268 | 144 | 0 |  |  |  |  |

[^2]${ }^{\mathrm{b}}$ A salmon tag was recovered from a seal stomach near Grand Manan (B. Beck, pers. comm.), but this was not reported in Bowen and Harrison 1996.
${ }^{\text {c As }}$ of April 1999, the number of published and unpublished harp seal stomach records in DFO files is $\sim 8300$, of which $\sim 6100$ contained food
(G. Stenson, DFO, pers. comm.)

Table 12
Sample sizes of kittiwake, gull, murre, and shearwater diet studies in Atlantic Canada.

| Predator | N | Number of samples containing salmon | Date | Region | Location | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Black-legged kittiwake | $69^{\text {a }}$ | NA | May-Sep 1966-1967 | Newfoundland | Witless Bay | Threlfall 1968 |
|  | NA | 0 | Late Jun-Aug 1969-1970 | Newfoundland | Gull I, Witless Bay | Maunder and Threlfall 1972 |
|  | 24 | 0 | Jul-Dec 1978-1984 | Fundy | Quoddy area | Braune 1987 |
| Great black-backed gull | $32^{\text {a }}$ | $N A^{\text {b }}$ | $\begin{gathered} \text { May-Sep 1966-1967 } \\ 1976-1978 \end{gathered}$ | Newfoundland Newfoundland | Witless Bay Witless Bay | Threlfall 1968 |
|  | $126^{\text {a }}$ |  |  |  |  | Pierotti 1979 in Good 1998 |
|  | 117 | 0 | 15 Jun-14 Jul 1994-1995 Jun-Aug 1969-1970 | St. Lawrence R Scotian Shelf | Islands in mid-estuary Sable I | Rail et al. 1996 Lock 1973 |
|  | $82^{\text {c }}$ | 0 |  |  |  |  |
| Herring gull | $401^{\text {a }}$ | NA | May-Sep 1966-1967 | Newfoundland | Witless Bay | Threlfall 1968 |
|  | $305^{\text {c }}$ | 0 | May-Aug 1976-1978 | Newfoundland | Great I, Witless Bay | Pierotti 1983 |
|  | 350 | 0 | 15 Jun-14 Jul 1994-1995 | St. Lawrence R | Islands in mid-estuary | Rail et al. 1996 |
|  | 22 | 0 | Jul-Dec 1978-1984 | Fundy | Quoddy area | Braune 1987 |
|  | 96 | 0 | 7 Jun-22 Jul 1994 | Southern Gulf | Carleton, Bay of Chaleur | Rail et al. 1996 |
|  | $N A^{\text {d }}$ | NA | 15 May-26 Jul 1986 | Southern Gulf | Kouchibouguac National Park | Martin and LaPierre $1986$ |
|  | $82^{\text {c }}$ | 0 | Jun-Aug 1969-1970 | Scotian Shelf | Sable I | Lock 1973 |
| Herring/great blackbacked gull | $537^{\text {a }}$ | NA | Mid May-mid Aug 1970-1971 | Newfoundland | Gull I, Witless Bay | Haycock and Threlfall 1975 |
| Common murre | 33 | 0 | 22 Jun-10 Aug 1981 late Jul-Aug 1982-1983 | Labrador Labrador | Near Gannet Islands Gannet Islands |  |
|  | 3,733 | 0 |  |  |  | Birkhead and |
|  |  |  |  |  |  | Nettleship 1987 |
|  | 44 | NA | Winter | Newfoundland |  | Tuck 1961 |
|  | 889 | $0^{\text {e }}$ | Jun-Aug 1982-1984 | Newfoundland <br> Newfoundland | Witless Bay | Piatt 1987 |
|  | $1012^{\text {f }}$ | $N A^{e}$ | late Jun-Jul 1982-1985 |  | Gull I, Witless Bay | Burger and Piatt 1990 |
| Thick-billed murre | 650 | 0 | late Jul-Aug 1982-1983 | Labrador | Gannet Islands | Birkhead and <br> Nettleship 1987 |
|  |  |  |  |  |  |  |
|  | 614 | NA | Winter | Newfoundland |  | Tuck 1961 |
|  | 46 | 0 | Winter 1981, 1983 | Newfoundland | Northeast coast | Gaston et al. 1983 |
|  | 1,200 | 0 | Winter 1984-1986 | Newfoundland |  | Elliot et al. 1990 |
| Greater shearwater | 38 | 0 | 26 June 1961 | Newfoundland Newfoundland Newfoundland Fundy | Eastern Grand Banks <br> Notre Dame Bay <br> Placentia Bay <br> Brier Island | Brown et al. 1981 <br> Brown et al. 1981 <br> Brown et al. 1981 <br> Brown et al. 1981 |
|  | 15 | 0 | 2nd week Sep 1975 |  |  |  |
|  | 20 | 0 | late June 1978 |  |  |  |
|  | 63 | 0 | 13 Aug-3 Sep 1974-1975 |  |  |  |
| Sooty shearwater | 20 | 0 | late June 1978 | Newfoundland Fundy | Placentia Bay Brier Island | Brown et al. 1981 <br> Brown et al. 1981 |
|  | 30 | 0 | 13 Aug-3 Sep 1974-1975 |  |  |  |

[^3]Table 13
Salmon consumption by seals and seabirds under various scenarios.

| Predator | Total annual food consumption in Atlantic Canada (t) ${ }^{\text {a }}$ | Prey consumption during vulnerability window $(t)^{b}$ | Mean salmon biomass during vulnerability window $(t)^{\text {C }}$ | Salmon consumption scenarios |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Predator consumes $1 \%$ of salmon cohort |  | Predator consumes 10\% of salmon cohort |  | Predator consumes entire salmon cohort |  |
|  |  |  |  | Percent salmon in predator diet | Fraction of prey that is salmon | Percent salmon in predator diet | Fraction of prey that is salmon | Percent salmon in predator diet | Fraction of prey that is salmon |
| Grey seal | 280,403 |  |  |  |  |  |  |  |  |
| Post-smolt predation |  | 117,539 | 798 | 0.0068 | 1/14,737 | 0.068 | 1/1,474 | 0.68 | 1/147 |
| 1SW predation |  | 129,830 | 934 | 0.0072 | 1/13,904 | 0.072 | 1/1,390 | 0.72 | 1/139 |
| Harbour seal | 5,664 |  |  |  |  |  |  |  |  |
| Post-smolt predation |  | 3,321 | 1,027 | 0.3093 | 1/323 | 3.093 | 1/32 | 30.93 | 1/3 |
| 1SW predation |  | 5,664 | 934 | 0.1649 | 1/606 | 1.649 | 1/61 | 16.49 | 1/6 |
| Harp seal | 3,127,951 |  |  |  |  |  |  |  |  |
| Post-smolt predation |  | 1,833,922 | 1,583 | 0.0009 | 1/115,821 | 0.009 | 1/11,582 | 0.09 | 1/1,158 |
| 1SW predation |  | 3,127,951 | 934 | 0.0003 | 1/334,898 | 0.003 | 1/33,490 | 0.03 | 1/3,349 |
| Hooded seal | 399,633 |  |  |  |  |  |  |  |  |
| Post-smolt predation |  | 33,941 | 1,583 | 0.0467 | 1/2,144 | 0.467 | 1/214 | 4.67 | 1/21 |
| 1SW predation |  | 199,269 | 934 | 0.0047 | 1/21,335 | 0.047 | 1/2,134 | 0.47 | 1/213 |
| Northern fulmar | 586,051 | 26,635 | 255 | 0.0096 | 1/10,444 | 0.096 | 1/1,044 | 0.96 | 1/104 |
| Shearwaters | 481,693 | 105,897 | 310 | 0.0029 | 1/34,146 | 0.029 | 1/3,415 | 0.29 | 1/341 |
| Black-legged kittiwake | 195,538 | 5,609 | 212 | 0.0378 | 1/2,644 | 0.378 | 1/264 | 3.78 | 1/26 |
| Gulls | 282,330 | 68,901 | 509 | 0.0074 | 1/13,534 | 0.074 | 1/1,353 | 0.74 | 1/135 |
| Common murre | 671,526 | 98,287 | 255 | 0.0026 | 1/38,542 | 0.026 | 1/3,854 | 0.26 | 1/385 |
| All predators | 6,030,789 |  |  |  |  |  |  |  |  |
| Post-smolt predation |  | 2,294,052 | 1,027 | 0.0004 | 1/223,363 | 0.004 | 1/22,336 | 0.04 | 1/2,234 |
| 1SW predation |  | 3,462,714 | 934 | 0.0003 | 1/370,740 | 0.003 | 1/37,074 | 0.03 | 1/3,707 |

[^4]Table 14
Food consumption by seabirds in eastern Canada, based on an energetics model by Diamond et al. 1993.

| Zone ${ }^{\text {a }}$ | $\begin{aligned} & \text { Area } \\ & \left(\mathrm{km}^{<}\right) \end{aligned}$ | Jan- <br> Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | $\begin{gathered} \text { Nov- } \\ \text { Dec } \end{gathered}$ | Total |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Energy demand (kJ/m ${ }^{2}$ per period) |  |  |  |  |  |  |  |  |  |  |  |
| Labrador Sea ${ }^{\text {b }}$ |  | 0.25 | 1.58 | 0.23 | 0.12 | 0.23 | 0.48 | 0.10 | 0.19 | 0.57 | 3.74 |
| N Labrador Banks |  | 1.89 | 0.74 | 1.02 | 0.22 | 0.43 | 0.99 | 0.46 | 2.04 | 0.48 | 8.27 |
| S Labrador Banks |  | 1.29 | 0.44 | 1.10 | 0.75 | 0.97 | 1.55 | 0.44 | 1.24 | 2.43 | 10.21 |
| Newfoundland Banks |  | 0.26 | 1.33 | 1.44 | 1.07 | 0.72 | 1.67 | 0.34 | 0.98 | 0.39 | 8.20 |
| Scotian Shelf |  | 0.21 | 0.28 | 0.17 | 0.34 | 0.41 | 0.29 | 0.28 | 0.35 | 0.58 | 2.91 |
| Gulf of St. Lawrence |  | 0.16 | 0.33 | 0.51 | 0.59 | 0.33 | 0.43 | 0.50 | 0.11 | 0.00 | 2.96 |
| Mean |  | 0.68 | 0.78 | 0.75 | 0.51 | 0.52 | 0.90 | 0.35 | 0.82 | 0.74 | 6.05 |
| Prey consumption (t) by zone ${ }^{\text {c }}$ |  |  |  |  |  |  |  |  |  |  |  |
| Labrador Sea | 984,894 | 48,279 | 304,159 | 44,417 | 22,208 | 44,417 | 92,696 | 18,346 | 36,692 | 110,076 | 721,290 |
| N Labrador Banks | 129,693 | 48,063 | 18,818 | 25,939 | 5,595 | 10,935 | 25,176 | 11,698 | 51,877 | 12,206 | 210,306 |
| S Labrador Banks | 189,471 | 47,925 | 16,347 | 40,866 | 27,863 | 36,037 | 57,584 | 16,347 | 46,068 | 90,278 | 379,314 |
| Newfoundland Banks | 571,413 | 29,131 | 149,016 | 161,340 | 119,885 | 80,670 | 187,110 | 38,094 | 109,801 | 43,696 | 918,743 |
| Scotian Shelf | 133,106 | 5,481 | 7,308 | 4,437 | 8,874 | 10,701 | 7,569 | 7,308 | 9,135 | 15,137 | 75,948 |
| Gulf of St. Lawrence | 214,000 | 6,714 | 13,847 | 21,400 | 24,757 | 13,847 | 18,043 | 20,980 | 4,616 | 0 | 124,204 |
| Total | 2,222,578 | 185,592 | 509,494 | 298,399 | 209,182 | 196,606 | 388,178 | 112,773 | 258,188 | 271,394 | 2,429,806 |

Prey consumption (t) by main predator species ${ }^{\circ}$ Northern fulmar

| Labrador Sea | 39,589 | 22,508 | 20,210 | 14,014 | 15,901 | 28,180 | 11,540 | 26,235 | 67,917 | 246,092 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| N Labrador Banks | 3,701 | 3,387 | 11,569 | 3,541 | 5,380 | 8,585 | 0 | 6,848 | 7,129 | 50,139 |
| S Labrador Banks | 33,548 | 12,996 | 11,770 | 1,337 | 12,793 | 20,558 | 2,795 | 12,991 | 61,660 | 170,447 |
| Newfoundland Banks | 7,632 | 14,902 | 22,265 | 2,877 | 3,630 | 21,331 | 2,819 | 19,545 | 17,828 | 112,828 |
| Scotian Shelf | 378 | 146 | 679 | 204 | 43 | 0 | 58 | 393 | 802 | 2,704 |
| Gulf of St. Lawrence | 161 |  | 364 | 693 | 1,066 | 198 | 1,280 | 78 |  | 3,841 |
| Total | 85,009 | 53,938 | 66,855 | 22,667 | 38,813 | 78,851 | 18,492 | 66,090 | 155,336 | 586,051 |
| Shearwaters |  |  |  |  |  |  |  |  |  |  |
| Labrador Sea | 0 | 0 | 0 | 4,486 | 14,480 | 46,348 | 789 | 220 | 0 | 66,323 |
| N Labrador Banks | 0 | 0 | 0 | 0 | 2,110 | 7,779 | 0 | 52 | 0 | 9,942 |
| S Labrador Banks | 0 | 0 | 0 | 3,539 | 16,505 | 25,798 | 7,552 | 1,106 | 1,083 | 55,582 |
| Newfoundland Banks | 0 | 298 | 13,230 | 31,889 | 47,837 | 142,204 | 24,037 | 58,744 | 5,025 | 323,264 |
| Scotian Shelf | 0 | 0 | 1,287 | 5,661 | 4,066 | 817 | 197 | 4,439 | 1,529 | 17,997 |
| Gulf of St. Lawrence | 0 |  | 0 | 74 | 1,952 | 1,732 | 4,825 | 0 |  | 8,584 |
| Total | 0 | 298 | 14,517 | 45,650 | 86,951 | 224,678 | 37,401 | 64,561 | 7,637 | 481,693 |
| Kittiwakes |  |  |  |  |  |  |  |  |  |  |
| Labrador Sea | 2,221 | 20,987 | 5,019 | 89 | 10,394 | 7,045 | 3,431 | 5,174 | 36,105 | 90,464 |
| N Labrador Banks | 1,154 | 1,186 | 3,943 | 45 | 1,028 | 3,424 | 1,345 | 3,580 | 867 | 16,570 |
| S Labrador Banks | 2,636 | 441 | 409 | 1,588 | 1,586 | 4,088 | 2,387 | 15,064 | 9,118 | 37,317 |
| Newfoundland Banks | 3,612 | 13,411 | 5,486 | 2,278 | 645 | 1,684 | 1,181 | 9,004 | 4,850 | 42,151 |
| Scotian Shelf | 263 | 7 | 9 | 35 | 0 | 136 | 132 | 375 | 288 | 1,245 |
| Gulf of St. Lawrence | 671 |  | 1,562 | 1,609 | 1,592 | 992 | 944 | 420 |  | 7,792 |
| Total | 10,557 | 36,033 | 16,427 | 5,644 | 15,245 | 17,370 | 9,419 | 33,615 | 51,228 | 195,538 |
| Gulls |  |  |  |  |  |  |  |  |  |  |
| Labrador Sea | 5,214 | 4,258 | 10,749 | 1,910 | 178 | 556 | 92 | 1,468 | 5,284 | 29,708 |
| N Labrador Banks | 2,740 | 9,202 | 7,107 | 0 | 350 | 2,014 | 3,439 | 2,334 | 2,075 | 29,262 |
| S Labrador Banks | 11,358 | 2,926 | 6,048 | 1,170 | 649 | 1,152 | 1,880 | 13,314 | 15,167 | 53,663 |
| Newfoundland Banks | 6,088 | 19,670 | 3,388 | 8,152 | 7,583 | 2,620 | 4,152 | 16,800 | 8,870 | 77,323 |
| Scotian Shelf | 3,623 | 6,022 | 1,358 | 2,076 | 5,907 | 6,085 | 3,135 | 2,393 | 12,171 | 42,769 |
| Gulf of St. Lawrence | 2,806 |  | 7,554 | 6,932 | 6,397 | 9,202 | 12,882 | 3,831 |  | 49,605 |
| Total | 31,829 | 42,078 | 36,204 | 20,241 | 21,063 | 21,629 | 25,580 | 40,140 | 43,566 | 282,330 |
| Murres |  |  |  |  |  |  |  |  |  |  |
| Labrador Sea | 193 | 256,406 | 7,551 | 1,910 | 178 | 556 | 1,266 | 587 | 3,082 | 271,728 |
| N Labrador Banks | 144 | 9,221 | 3,320 | 2,008 | 940 | 1,133 | 0 | 38,130 | 1,477 | 56,374 |
| S Labrador Banks | 192 | 0 | 17,491 | 14,851 | 2,054 | 1,324 | 1,291 | 1,382 | 2,528 | 41,113 |
| Newfoundland Banks | 6,176 | 93,284 | 95,191 | 67,975 | 11,536 | 936 | 38 | 1,867 | 3,976 | 280,977 |
| Scotian Shelf | 428 | 175 | 204 | 9 | 0 | 0 | 0 | 9 | 30 | 855 |
| Gulf of St. Lawrence | 779 |  | 8,432 | 9,457 | 1,454 | 162 | 0 | 194 |  | 20,478 |
| Total | 7,911 | 359,086 | 132,188 | 96,210 | 16,162 | 4,111 | 2,595 | 42,168 | 11,094 | 671,526 |

${ }^{\mathrm{a}}$ Diamond et al. 1993 define zones as follows: Labrador Sea - from the edge of the continental shelf to $45^{\circ} \mathrm{W}$ and $60^{\circ} \mathrm{N}$;
Northern Labrador Banks - the continental shelf from $60^{\circ} \mathrm{N}$ to $53^{\circ} \mathrm{N}$; Southern Labrador Banks - the continental shelf from $53^{\circ} \mathrm{N}$ to $50^{\circ} \mathrm{N}$; Newfoundland Banks - the continental shelf east, southeast, and south of Newfoundland.
${ }^{\mathrm{b}}$ Figures given by Diamond et al. (1993) for the Labrador Sea are reduced by $50 \%$, to compensate for overestimation due to the concentration of survey effort near the edge of the continental shelf, where birds tend to congregate.
${ }^{\mathrm{c}}$ Energy demands $\left(\mathrm{kJ} / \mathrm{m}^{2}\right)$ supplied by Diamond et al. 1993 were converted to harvests by assuming 1 g wet weight contains 5.1 kJ (mean of energy densities compiled by Cairns 1998).

Table 15
Estimated harvest of Atlantic salmon by grey, harbour, and harp seals and by common murres, based on post-1980 records of salmon predation (Table 10). Calculations are based on
frequency of occurrence (except where noted), which may not accurately reflect the contribution of salmon to the diet.

| Predator | Number of stomachs containing salmon <br> A | Number of salmon per stomach | Number of fish per food-containing stomach |  | Number <br> of samples with full ID <br> D | Salmon as a percent of $\operatorname{diet}^{a}$ | Total prey harvest in eastern Canada | Estimated salmon harvest <br> (t) | Meansalmonbiomass ( t )duringwindow ofvulnerability | Salmon harvest <br> as a percent of biomass | Salmon harvest estimates from Hammill and Stenson 1997 |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | Mean | Source |  |  |  |  |  |  |  |  |
|  |  |  | C |  |  |  |  |  |  |  | Harvest <br> (t) | $\begin{aligned} & \hline \text { Percent } \\ & \text { of } \\ & \text { biomass } \end{aligned}$ |
| Grey seal | 1 | 6 | 1.41 | Benoit and Bowen 1990a | 1,094 | 0.389 | 280,403 | 1,089.6 | 934 | 116.7 | 712 | 76.2 |
| Harbour seal | 1 | 1 | 6.75 | Bowen and Harrison 1996 | 648 | 0.023 | 5,664 | 1.3 | 934 | 0.1 | 0 | 0.0 |
| Harp seal |  |  |  |  |  |  |  |  |  |  |  |  |
| Brighton | 1 | 1 | 26.82 | Lawson et al. 1995 | 6,100 | 0.0006 |  |  |  |  |  |  |
| Escoumins | 1 | 1 |  |  | 6,100 | $0.0028{ }^{\text {b }}$ |  |  |  |  |  |  |
| Total |  |  |  |  |  | 0.0034 | 3,127,953 | 106.3 | 934 | 11.4 | 2,474 | 264.9 |
| Common murre | 1 | 1 | 0.99 | Piatt 1987 | 3,766 | 0.027 | 248,672 ${ }^{\text {c }}$ | 66.6 | 255 | 26.1 | - | - |

## ${ }^{\text {a }}$ Calculated as $\mathbf{E}=\left(100^{*} \mathbf{A}^{*} \mathbf{B} / \mathbf{C}\right) / \mathbf{F}$

${ }^{\text {b }}$ Salmon constituted 0.17 of the prey contents of one stomach (Table 8). Salmon as a percent of diet was calculated as $100 * 0.17 / 6,100$
${ }^{\text {c Based on }}$ estimated harvest by murres from May to August, to exclude wintering thick-billed murres.


Fig. 1
Composite length growth of post-smolt Atlantic salmon, from river exodus to October. The logistic curve is fitted to anchor points representing mean lengths of smolts in the Miramichi River (Allen et al. 1972), of post-smolts captured by gannets on Funk Island in August (Montevecchi unpubl.), and of post-smolts captured in research cruises in the Labrador Sea in September-October. Bay of Fundy data are from Allen et al. 1972 and NW Gulf of St. Lawrence data are from Dutil and Coutu 1988.


Fig. 2
Composite length growth of Atlantic salmon, sea age 0 to 2 years. The logistic curve is fitted to anchor points representing mean lengths of smolts in the Miramichi River (Allen et al. 1972), of post-smolts captured by gannets on Funk Island in August (Montevecchi unpubl.), of post-smolts taken in research cruises in the Labrador Sea in September-October, and of 1 sea winter and 2 sea winter virgin salmon returning to the Miramichi River (Moore et al. 1995).


Fig. 3
Composite weight growth of post-smolt Atlantic salmon, from river exodus to October. The logistic curve is fitted to anchor points representing mean weights of smolts in the Miramichi River (R.A. Cunjak unpubl.), of post-smolts captured by gannets on Funk Island in August (Montevecchi unpubl.) and of post-smolts taken in research cruises in the Labrador Sea in September-October. NW Gulf of St. Lawrence data are from Dutil and Coutu 1988.


Fig. 4
Composite weight growth of Atlantic salmon, sea age 0 to 2 years. The logistic curve is fitted to anchor points representing mean weights of smolts in the Miramichi River (R.A. Cunjak unpubl.), of post-smolts captured by gannets on Funk Island in July-August (Montevecchi unpubl.), of post-smolts taken in research cruises in the Labrador Sea in September-October, and of 1 sea winter and 2 sea winter virgin salmon returning to the Miramichi River (Moore et al. 1995).


Fig. 5
Estimated daily instantaneous mortality of North American salmon from river exodus to sea age 1 year. Curves are calculated from the mean estimated smolt run and the mean estimated 1SW pre-fishery abundance for smolt years 1990 to 1996.


Fig. 6
Estimated number of North American salmon alive between river exit and sea age 1 year. Curves are calculated from the mean estimated smolt run and the mean estimated 1SW pre-fishery abundance for smolt years 1990 to 1996.


Fig. 7
Estimated biomass of North American Atlantic salmon from river exodus to sea age 1 year. Curves are calculated from the mean estimated smolt run and the mean estimated 1SW pre-fishery abundance for smolt years 1990 to 1996.


[^0]:    ${ }^{\text {a }}$ Recaptured in either June or July

[^1]:    ${ }^{4}$ Prey sizes in cm except where noted
    ${ }^{\mathrm{D}}$ Includes fish from razorbill and Atlantic puffin samples

[^2]:    

[^3]:    ${ }^{\text {a }}$ Fish in samples were not identified to species
    ${ }^{\mathrm{b}}$ Great black-backed gulls were observed feeding on salmon which had been caught in surface-set gillnets.
    ${ }^{\text {c }}$ Some fish were not identified to species
    ${ }^{\mathrm{d}}$ Most fish were not identified to species
    ${ }^{\text {e }}$ Data reported by Piatt 1987 and Burger and Piatt 1990 overlap. A salmon tag was found in a murre stomach (Montevecchi et al. 1988), but was not reported in either study.
    ${ }^{\mathrm{f}}$ Fish other than capelin and sand lance were not identified

[^4]:    ${ }^{2}$ For seals, estimates are for eastern Canadian waters up to the northern boundary of NAFO area 2 J (data from Hammill and Stenson 1997). For seabirds, estimates are for eastern Canadian waters to $60^{\circ} \mathrm{N}$ (data from Diamond et al. 1993 as re-analysed in Table 12) ${ }^{\mathrm{b}}$ For seals, estimates are from Hammill and Stenson 1997 pro-rated for the period of vulnerability. For seabirds, from Table 14.
    ${ }^{c}$ From the northwest Atlantic salmon biomass estimated from 1990-1996 data, and assuming $20 \%$ mortality upon river exit. For seal predation on 1SW salmon, biomass is the product of weight at 1 July in the 1SW year and mean pre-fishery abundance.

